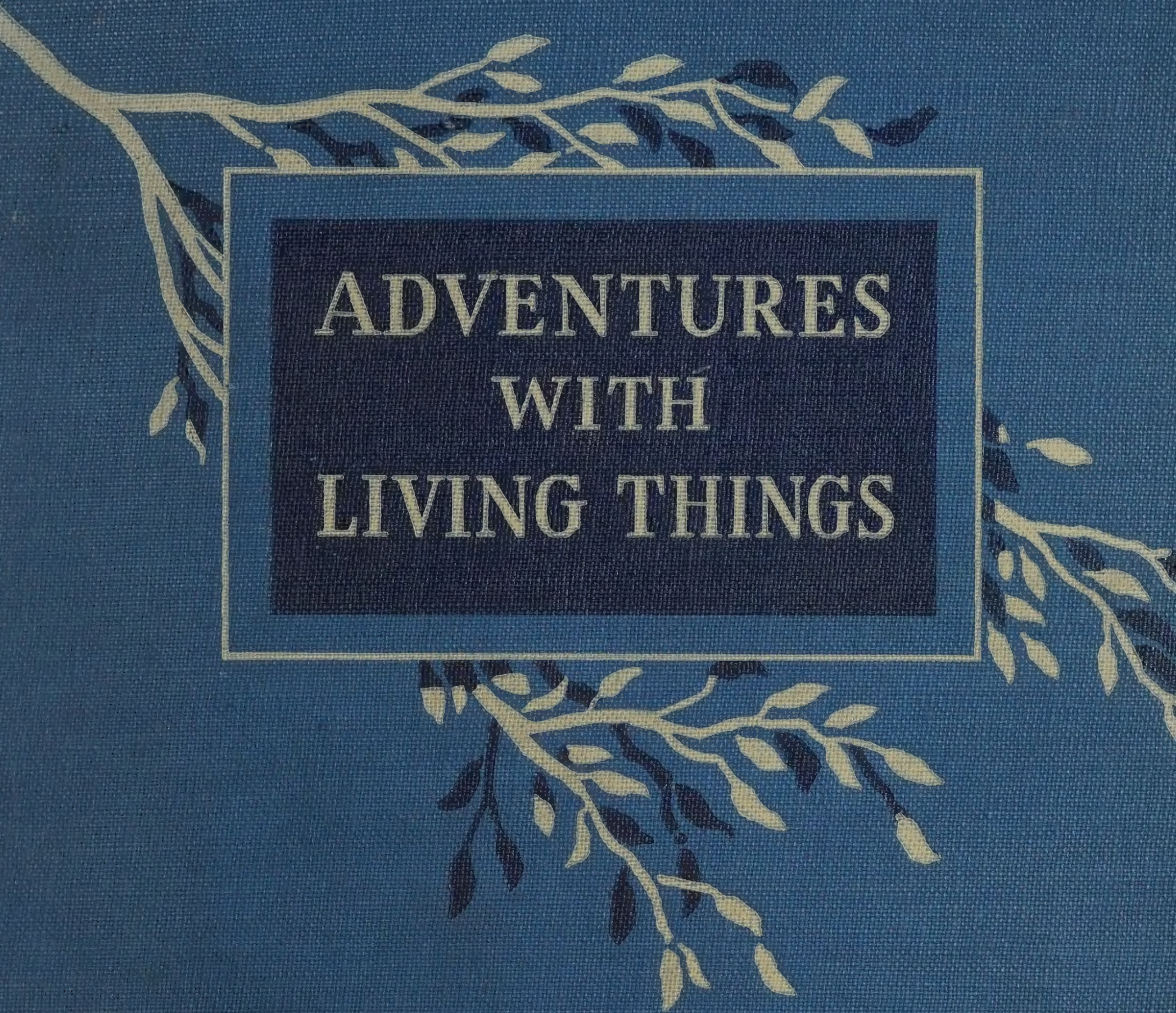


ADVENTURES WITH LIVING THINGS

ELSBETH KROEBER WALTER H. WOLFF

Digitized by the Internet Archive
in 2026 with funding from
University of Toronto

https://archive.org/details/adventureswithli00kroe_0

Photo by M. A. Fenton

MODERN MAN AND ANCIENT (FOSSIL) LIFE MEET ABOVE AN IOWA CORNFIELD

BI
K

Adventures With Living Things

A GENERAL BIOLOGY

ELSBETH KROEBER
Chairman, Department of Biology
James Madison High School, New York City

WALTER H. WOLFF
Chairman, Department of Biology and General Science
DeWitt Clinton High School, New York City
Instructor, School of Education
College of the City of New York

UNIVERSITY OF TORONTO LIBRARY

398013
17.11.41

D. C. HEATH AND COMPANY
BOSTON NEW YORK CHICAGO
ATLANTA SAN FRANCISCO DALLAS
LONDON

Copyright, 1938
By D. C. Heath and Company

No part of the material covered by this copyright may be reproduced in any form without written permission of the publisher.

3 C 9

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

The name *Adventures with Living Things* expresses in large measure our conviction that the study of biology can be made an exciting adventure for the boys and girls who undertake it. We have conceived of this adventure as many-faceted; it includes the explorer's interest in the living things of this earth, every person's curiosity about the way in which plants and animals live, and a plumbing of the great generalizations of the science that touches upon man's welfare more closely than does any other. Biology is thus presented as a unified whole, not as the sum of two separate entities, botany and zoology.

The basic fact that boys and girls grow rapidly in ability to comprehend generalizations led us to develop a content organization in which the three parts of the book represent increasingly higher levels of subject matter treatment. Part 1 is a simple descriptive account of the living things of this earth. Subject matter of this nature provides the young reader with textual material which is interesting and easily grasped and made his own. Part 2, through the functional approach and the organization of facts around simple concepts, gives the student an elementary understanding of the ways in which he himself and all other organisms live and reproduce. Part 3, which presents the great generalizations of biology, is designed particularly for such a course as is being developed in New York City and in other parts of the country.

An attempt has been made to achieve simplicity of expression not only by the exclusion of difficult words but in the phrasing of sentences. In our experience, students face two difficulties in the use of a text. One is the barrier which the technical term erects between the student and the idea; the other is created by a summary treatment of content with abrupt transitions from idea to idea so that the student is not carried forward gradually from each sentence to the next. We have made a painstaking attempt to escape these defects. The use of the text in mimeographed form and the criticisms of other teachers and of pupils have helped us to approximate this ideal.

Since we intended to subordinate facts to ideas and to present the data of biology in such fashion that they would lead to understandings, the content in Parts 2 and 3 is in unit form. In Part 2 each paragraph develops an idea; the several paragraphs in a problem provide an answer to the problem question; the answers to the problem questions provide an answer to the unit question that is the unit title. In Part 3 the presentation is similar, but generalizations take the place of questions. We refrained from using the unit organization in Part 1 in order that it might be truly descriptive.

Recent developments in the teaching of biology have stressed the inculcation of scientific attitudes and the development of the habit of using the scientific method wherever it is applicable. This objective, in the experience of many teachers, is best achieved if it is not didactically presented. The text, therefore, has been carefully written so that it implies and incorporates the scientific attitude of mind and the scientific method of arriving at conclusions; but there are few references to the method as something apart from the life of the pupil or from the study of biological principles.

At the end of each unit there are large numbers of exercises, problems for classroom discussion, supplementary activities for the junior biologist, and a bibliography. Since it is our conviction that we are more likely to obey the dictates of a hygienic principle when we have arrived at it independently, some of the exercises and problems for classroom discussion in Part 2 have been used as a means of developing hygienic applications. The illustrations have been carefully chosen to form an integral part of the text. Many of them may be used as a basis for questions and exercises.

During the preparation of this book, we examined the major syllabuses, both city and state, in use throughout the country in both the ninth and tenth years. This study included the recent proposed General Biology syllabus of New York State as well as the principles set forth in the Thirty-First Yearbook. Analysis of these helped us to weave into a coherent and teachable whole a body of content suitable for the various courses of study.

ELSBETH KROEBER
June, 1938 WALTER H. WOLFF

ACKNOWLEDGMENTS

The authors wish to thank the following for their assistance in the preparation of the manuscript.

Dr. Elsie Kupfer, Chairman, Department of Biology, Wadleigh High School, New York City, for critical reading of the whole manuscript

Dr. Anita D. Laton, Lecturer in Education and Supervisor of the Teaching of Science, University High School, University of California, for critical reading of the whole manuscript

Mr. Ben Bauman, DeWitt Clinton High School, New York City, for critical reading of Parts 1 and 3 in manuscript

Dr. Harold R. Hagan, College of the City of New York, for critical reading of portions of the manuscript

Dr. Stuart K. Harris, Instructor in Biology, Boston University, for critical reading of portions of the manuscript

Dr. Arthur T. Henrici, Medical School, University of Minnesota, for critical reading of portions of the manuscript

Dr. H. H. Johnson, College of the City of New York, for critical reading of portions of the manuscript

Dr. A. L. Kroeber, University of California, for critical reading of portions of the manuscript

Professor Laurence H. Snyder, Department of Zoology, Ohio State University, for critical reading of portions of the manuscript

Dr. John Thompson, Fatigue Laboratory, Harvard University, for critical reading of portions of the manuscript

Dr. Robert I. Wolff, College of the City of New York, for critical reading of portions of the manuscript

Mr. Nelson S. Kline, Chairman, Department of Biology, Manual Training High School, Brooklyn, N. Y., for the use of photomicrographs

Miss Rose Robbins, James Madison High School, New York City, for critical reading of portions of the manuscript

Mr. David Schiff, James Madison High School, New York City, for compilation of data used in certain tables and charts

Mr. H. Schneider, DeWitt Clinton High School, New York City, for photographs taken especially for the book

Mr. J. Schwartz, DeWitt Clinton High School, New York City, for photographs taken especially for the book

Mr. C. J. Sullivan, DeWitt Clinton High School, New York City, for photographs taken especially for the book

Mr. Albert Valenstein, High School of Music and Art, New York City, for assistance with various pupil activities and critical reading of portions of the page proofs

Miss Josette Frank, the Child Study Association, for assistance with the bibliography

Dr. Walter Granger, American Museum of Natural History, New York City, for critical reading of portions of the manuscript

Mr. Robert Cushman Murphy, American Museum of Natural History, Professor Hugh Davis, and Mr. C. Brown, Photography Editor, *Nature Study Magazine*, for the use of photographs

Mrs. Selina T. Johnson for drawings and diagrams

CONTENTS

PART 1. THE MANY LIVING THINGS OF THIS EARTH

Directions for Study xii

Overview: THE BIOLOGIST AFIELD 1

Chapter I. THE SORTING OF ANIMALS AND PLANTS 13

II. GETTING ACQUAINTED WITH MAMMALS 25

III. GETTING ACQUAINTED WITH BIRDS 36

IV. GETTING ACQUAINTED WITH REPTILES AND AMPHIBIA 51

V. GETTING ACQUAINTED WITH FISHES 65

VI. THE INSECTS 73

VII. OTHER ARTHROPODS 94

VIII. OTHER INVERTEBRATES 103
  1. SOFT-BODIED ANIMALS 103
  2. THE FIVE-RAYED ANIMALS 107
  3. WORMS OF VARIOUS KINDS 109
  4. THE MOST BEAUTIFUL ANIMALS OF THE SEA 112
  5. ANIMALS RIDDLED WITH HOLES 116

IX. THE "INVISIBLE" ORGANISMS 120

X. THE PLANTS WITHOUT FLOWERS 129

XI. THE FLOWERING PLANTS 140

PART 2. HOW PLANTS AND ANIMALS LIVE

To the Student 158

Overview: THE BIOLOGIST IN THE LABORATORY 159

Unit I. WHAT HAVE ANIMALS AND PLANTS IN COMMON? 167
  Problem 1. HOW DO LIVING AND LIFELESS THINGS DIFFER FROM ONE ANOTHER? 167

Problem 2. WHAT HAVE SCIENTISTS LEARNED ABOUT THE PROTOPLASM COMMON TO ANIMALS AND PLANTS? 178

Unit II. HOW DO PLANTS AND ANIMALS OBTAIN THEIR FOOD? 191
Problem 1. HOW DO GREEN PLANTS "EAT"? 191
Problem 2. HOW DO GREEN PLANTS USE THE SIMPLE COMPOUNDS THEY TAKE IN? 205
Problem 3. HOW DO ANIMALS GET THEIR FOOD? 213

Unit III. HOW DO ANIMALS AND PLANTS USE THEIR FOOD? 224
Problem 1. HOW DO LIVING THINGS GROW? 224
Problem 2. HOW ELSE DO ANIMALS AND PLANTS USE FOOD? 231
Problem 3. HOW SHOULD MAN PLAN HIS DIET TO MAKE THE WISEST USE OF HIS FOOD? 242

Unit IV. HOW DO LIVING THINGS PREPARE FOOD SO THAT IT CAN BE USED FOR ASSIMILATION AND OXIDATION? 261
Problem 1. WHAT SORT OF PREPARATION OF FOOD TAKES PLACE IN ALL ORGANISMS? 261
Problem 2. HOW DOES THE HUMAN BODY PREPARE ITS FOOD FOR USE IN THE CELL? 268
Problem 3. WHAT INTERESTING VARIATIONS IN DIGESTION ARE FOUND IN OTHER ORGANISMS? 283

Unit V. HOW ARE THE NEEDS OF CELLS SUPPLIED IN PLANTS AND ANIMALS? 290
Problem 1. HOW ARE MATERIALS TRANSPORTED TO AND FROM THE CELLS IN MAN AND OTHER ANIMALS? 290
Problem 2. HOW DOES OXYGEN ENTER THE BLOOD STREAM? 308
Problem 3. HOW ARE THE CELLS OF THE BODY BENEFITED BY THE GIVING OFF OF WASTES FORMED IN OXIDATION? 320
Problem 4. HOW ARE CELL ACTIVITIES REGULATED IN HIGHER ANIMALS? 329
Problem 5. HOW DOES THE HIGHER PLANT SUPPLY THE NEEDS OF ITS CELLS? 342

Unit VI. WHY DO LIVING THINGS BEHAVE AS THEY DO? 358
Problem 1. WHY DO PROTOZOA BEHAVE AS THEY DO? 358
Problem 2. HOW DOES THE BEHAVIOR OF COMPLEX PLANTS COMPARE WITH THAT OF PROTOZOA? 362
Problem 3. HOW DOES THE STRUCTURE OF MANY-CELLED ANIMALS ENABLE THEM TO RECEIVE STIMULI AND RESPOND TO THEM? 368

Problem 4. What Kinds of Behavior Are Found in the Many-celled Animals? 380

Problem 5. How Are the Higher Animals Fitted for Their More Complex Behavior? 399

Unit VII. How Do Living Things Reproduce? 408

Problem 1. What Is the Simplest Way for Animals and Plants to Make More of Their Own Kind? 408

Problem 2. What Are the More Complicated Forms of Reproduction? 418

Problem 3. How Is Sexual Reproduction Carried On in the More Complex Animals? 422

Problem 4. How Does Sexual Reproduction Take Place in Ferns and Flowering Plants? 438

Problem 5. On What Factors Does Successful Reproduction Depend? 450

Unit VIII. How Are Plants and Animals Fitted to Survive? 461

Problem 1. How Do Plants and Animals Meet the Various Physical Conditions of Their Environments? 461

Problem 2. How Do Organisms Injure One Another? 474

Problem 3. What Means of Defense Do Plants and Animals Use against Their Foes? 485

Unit IX. What Methods Does Man Use in the Struggle with Other Organisms? 500

Problem 1. In What Ways Has Science Taught Man to Fortify His Body against the Bacteria of Disease? 500

A. How Does Man Study Bacteria? 500

B. How Did the New Techniques Enable Man to Fortify His Body against the Bacteria of Disease? 507

Problem 2. What Methods Does Man Use to Keep Harmful Microorganisms at a Distance? 523

Problem 3. What Measures Are Used by Man to Defend Himself against the Larger Competing Organisms? 534

PART 3. GREAT GENERALIZATIONS OF BIOLOGY

Unit X. There Is Unity in All Living Things 548

1. Living Things Are Basically Alike in Structure and Function 548

2. Living Things Show Various Degrees of Resemblance to One Another 561

Unit XI. THERE IS A BALANCE OF LIFE ON THIS PLANET 571

1. THE REPEATED USE OF EARTH MATERIALS MAKES POSSIBLE THE CONTINUED EXISTENCE OF PLANTS AND ANIMALS 571

2. WITHIN A SMALL AREA TEMPORARY SHIFTS IN BALANCE ARE THE RULE; NORMALLY THEY RIGHT THEMSELVES 580

3. MAN TENDS TO DISTURB THE BALANCE OF LIFE 587

4. MAN IS BEGINNING TO UNDERSTAND AND CONTROL PLANT-ANIMAL RELATIONSHIPS 599

Unit XII. CONSTANT CHANGE IS CHARACTERISTIC OF THE EARTH AND ITS INHABITANTS 610

1. CHANGES ARE CONSTANTLY TAKING PLACE IN THE SURFACE OF THE EARTH 610

2. THE STUDY OF THE ROCKS ENABLES MAN TO RECONSTRUCT THE HISTORY OF THE EARTH AND ITS INHABITANTS 618

3. AT VARIOUS STAGES IN ITS HISTORY THE EARTH PRESENTED VERY DIFFERENT SCENES 633

Unit XIII. THE ORGANISM IS THE PRODUCT OF ITS HEREDITY AND ENVIRONMENT WORKING TOGETHER 648

1. A BRIDGE OF PROTOPLASM FROM GENERATION TO GENERATION RESULTS IN OFFSPRING OF THE SAME GENERAL KIND AS THE PARENTS 648

2. THE TRANSMISSION OF GENES RESULTS IN DIFFERENCES AS WELL AS LIKENESSES BETWEEN PARENTS AND OFFSPRING 661

3. SOME DIFFERENCES BETWEEN PARENTS AND OFFSPRING ARE THE RESULT OF CHANGES IN GENES AND CHROMOSOMES; THESE BREED TRUE 681

4. SOME DIFFERENCES AMONG INDIVIDUALS OF THE SAME SPECIES ARE CAUSED BY THE ENVIRONMENT 688

Unit XIV. THE ACCUMULATION OF SMALL CHANGES IN ORGANISMS THROUGHOUT THE AGES HAS PRODUCED THE MANY TYPES OF TODAY 697

1. SMALL CHANGES IN TYPES OF LIVING THINGS CAN BE PRODUCED BY MAN'S EFFORTS 697

2. THE SEQUENCE OF FOSSILS IN THE ROCKS INDICATES THAT THE VARIOUS TYPES OF PLANTS AND ANIMALS ORIGINATED FROM DIFFERENT TYPES THAT PRECEDED THEM 715

3. SCIENTISTS HAVE DEVELOPED THEORIES TO EXPLAIN HOW NEW TYPES MAY DEVELOP FROM PRECEDING TYPES 724

4. AN UNDERSTANDING OF THE ORIGIN OF SPECIES HAS MADE IT POSSIBLE TO EXPLAIN MANY PUZZLING BIOLOGICAL FACTS 733

Unit XV. THE FUTURE OF MANKIND IS RICH WITH POSSIBILITIES OF BETTERMENT 744

1. MAN HAS BEEN LONG IN THE MAKING 744

2. SCIENCE POINTS THE WAY TOWARD HUMAN IMPROVEMENT 756

Index 773

DIRECTIONS FOR STUDY

Most of us, even grownups, do not know how to read. When we are very young our elders struggle with us until we have mastered "reading." But, too often, all they teach us is how to recognize words in print or script. We have learned to read in one sense, but we have not been taught to get as much as possible from the book. That is quite a different skill.

Many people think the way to get ideas from a book is to read a passage over and over. That merely results in memorizing. And memorizing is quite different from understanding. You might learn these words by heart and perhaps be able to recite them word for word twenty years from now, and yet *understand nothing* of what is in these sentences.

How then should you study your textbook? In the first place, it is absolutely necessary that you *know what you are trying to read about or understand.* If someone seated you, blindfolded, and surrounded you with a wheel, with levers, pedals, and so on, and did not tell you that you were to learn to drive a car but taught you to move first one thing then another, would you ever learn anything worth while? That is just about what you are doing when you begin to read a chapter without really knowing what the chapter will be about; or a paragraph without really knowing what the paragraph title is. Of course, you automatically read the heading but usually it makes no impression on you. This is what you should do: Read the title and think over the meaning of the words, and ask yourself what you already know about that subject. *Do not begin to read your text until you have thought over the paragraph title.*

In the second place, a great help to understanding the text is to look closely at the pictures. But you will not be sure that you are getting the full meaning of the picture unless you read the statements and the questions that accompany it. This is just as important as reading the text itself.

In the third place, when you read a sentence, a phrase, or even a word that you do not understand, *always stop.* If it is a word, look it up or ask someone its meaning. If it is a sentence, read it again. If you still do not understand, read on a little way to see whether its meaning becomes clear. If this does not help, if the sentence still is not clear, jot it down to have it explained in class. *Never pass over anything that you do not understand* without making every possible effort to have it explained. If you follow this rule you will become surprisingly skillful in discovering the full meaning of the author.

In the fourth place, reading with understanding implies that you are thinking. If your brain is active, all kinds of questions and problems will arise in your mind as you read. If no thoughts of your own come to you, you are probably not doing your reading in the right way. Make a careful note of all your questions and present them to the class the next day. This is what makes class discussions interesting.

Lastly, you can never understand what you are reading in biology unless you learn to speak the language of the biologist. That means that you must know the meaning of certain biological words. Those that are necessary to an understanding of this book, or those that should form part of the vocabulary of every educated person, are printed so that they stand out. You will find it very helpful to do the following: In the notebook in which you will be writing your summaries, set apart one page under every chapter and write there each new biological term as it appears in the text. Be sure that you can pronounce it easily, that you can spell it, and can tell in simple words what it means. On every occasion use the new term so as to make it a part of your active vocabulary.

PART 1

THE MANY LIVING THINGS OF THIS EARTH

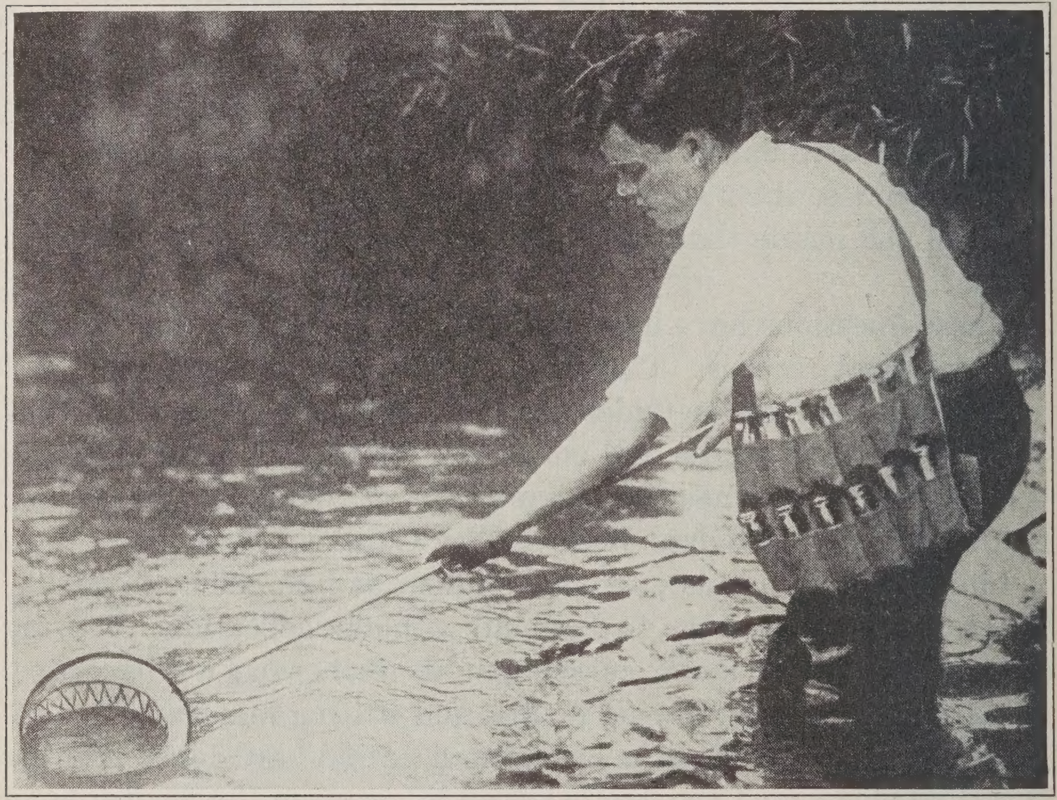
OVERVIEW: THE BIOLOGIST AFIELD

The biologist explores the world. Do you know what kinds of plants and animals live on this earth? Do you know what plants and animals live on the island of Borneo or up the Amazon River? Could you describe a scene in the Gobi Desert of Asia or picture to yourself the plants that make summer beautiful within the Arctic Circle?

These questions have interested man for as long a time as there are historical records. Centuries ago there were men bold and adventurous enough to undertake long voyages to distant parts of the earth merely to see and collect the plants and animals living there. One of the most important trips of this kind was the one made about two hundred years ago by Carolus Linnaeus.

Linnaeus (Lin-nee′us), a young student at a Swedish university, was sent by his country to Lapland to make collections of living things. He started alone, carrying in his leather bag a microscope, a telescope, paper for drying plants, and writing materials for taking notes. For five months he endured untold hardships. During this time he reached the Arctic Ocean by crossing the peninsula on foot. Then he returned to his university with a few specimens of rocks and animals and plants, and complete notes on everything he had seen. He had learned a great deal about the customs of the native Lapps, had become acquainted with the wild animals of the country, and had made a thorough study of the plants, for *botany* (the study of plants) was the subject of greatest interest to him. It is said that he traveled more than four thousand miles at a cost of about one hundred and twenty-five dollars.

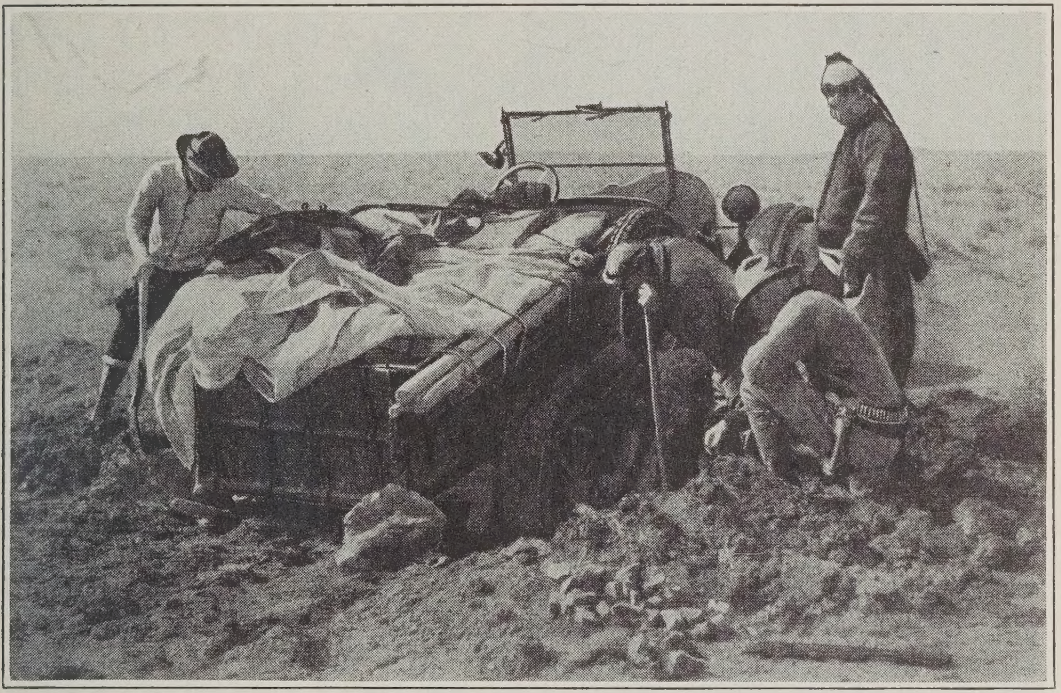
Linnaeus's accounts of his journey inspired other *biologists* (people who study plants and animals) to explore foreign lands. There have been many scientific explorations since then. Often these trips lasted for several years during which the biologist was far from any civilized country, completely dependent upon his skill with the gun and his ability to make friends with the native tribes. Sometimes the natives were interested and friendly, sometimes they were savages, hostile or suspicious of the stranger who could not understand their tongue. He had to win their confidence slowly, learn their language, and persuade them to take long trips on foot, on horseback, or by boat through parts of the country the natives feared. Here the explorer pitched camp so that he could devote himself to his search for new types of animals and plants. Many of these were collected and stored to be taken back to museums and universities. Complete notes were kept of all observations so that no mistake would be made later when the scientific reports were being prepared. Some of these exploring scientists were also excellent artists and prepared their own sketches of the strange scenes they saw.



Courtesy General Biological Supply House

FIG. 1. A modern collector hunts for water-living animals and plants. What equipment does he need?

One of the most famous of the nineteenth century scientist-explorers was Alfred Russel Wallace, who with a companion, Henry Walter Bates, fought his way through the jungles of Brazil, observing, recording, and collecting the many living things that inhabit the dark tropical forests along the Amazon. After two years he returned to England; Bates remained behind to continue his valuable studies. Wallace then turned eastward, sailing for the East Indies, a long voyage in those days. Suffering terrific discomfort in the heat, exposed to tropical diseases and many dangers, he remained in these islands for years. His careful observations and thoughtful study enabled him to make important biological discoveries of which you will read later.

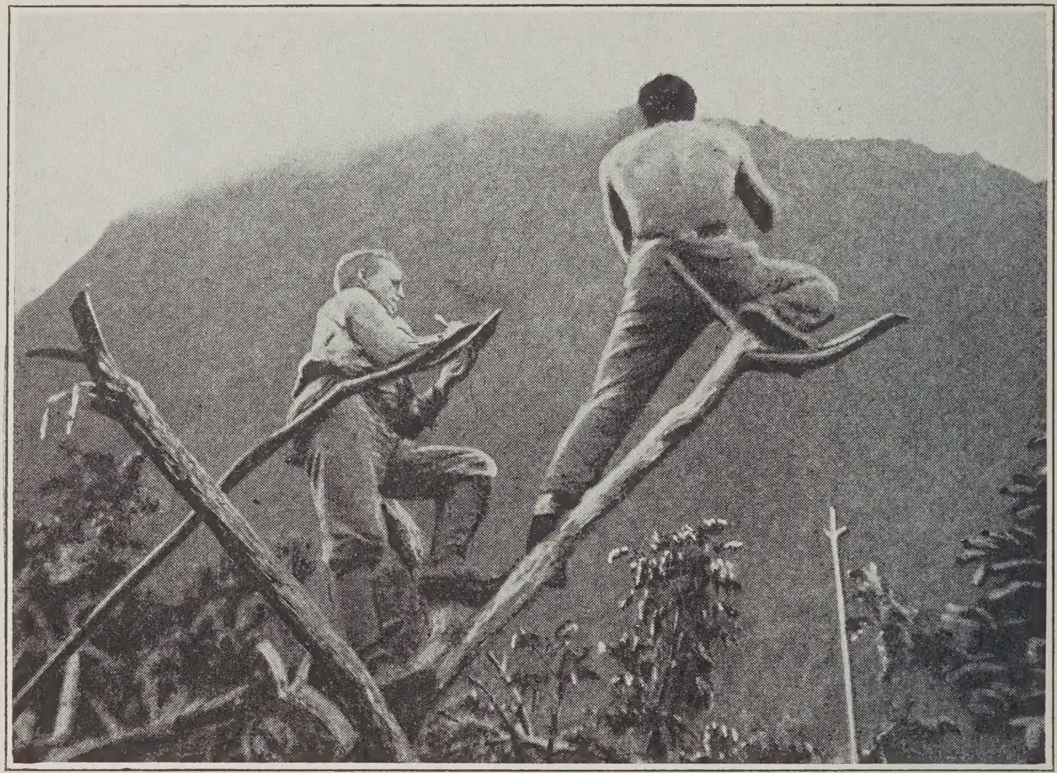


Courtesy American Museum of Natural History

FIG. 2. The Central Asiatic Expedition of the American Museum of Natural History meets with an accident in the Mongolian Desert. What abilities must the explorer have besides knowledge of his subject?

Exploring is not at an end. Exploring nowadays is frequently of a different kind. Huge expeditions are organized, equipped with scientific instruments of many kinds and manned by experts in every science. There are experts on rocks and soil, experts on plants, experts on birds, on snakes and on other kinds of animals; photographers and secretary-historians to take care of the collections and notes.

Despite their size and organization, such expeditions still meet with exciting adventures. The expeditions of the American Museum of Natural History, working in the Mongolian deserts, have met with warlike tribes, fierce storms, deep mud in which their automobiles sank to the fenders, and the discomforts of blazing days and icy nights. Specimens that had been carefully packed for shipment across half the world have had to be carried by automobile or camel across desert wastes, guarded constantly against accidents and the menace of fierce sandstorms.



Courtesy American Museum of Natural History

FIG. 3. Taking notes under difficulties on the island of Tahiti.

Exploring is not at an end. Though many expeditions have been made and vast numbers of books have been written describing them, there is still much to be learned. Even as you read this, investigators are at work in the field in all parts of the world. The more man learns about living things the more there seems left for him to learn. In newspapers and magazines you can read accounts of the explorations now going on; perhaps of a huge undertaking to explore half a continent, or of a journey lasting many months or years made alone by an expert to a faraway tiny island in the Pacific to study birds. You will discover that biologists search high in the mountains, and deep in the sea, in the frozen wastes of the arctic and in the hot, wet jungles, seeking to learn about the animals and plants of this earth.

Exploring the depths of the ocean. You may join exploring biologists in imagination, if you will. Would you care to stroll through a garden in the warm seas twenty feet below the surface? Get into your bathing suit, strap your diving helmet to your shoulders, and climb down the ladder that hangs over the boat's side. When you reach the last rung, drop off. You will sink gently to the bottom. Take care not to scratch yourself on the corals that are part of the lovely undersea gardens. If you have remembered your zinc pad and lead pencil you will be able to take notes as soon as your eyes grow accustomed to the dim light.

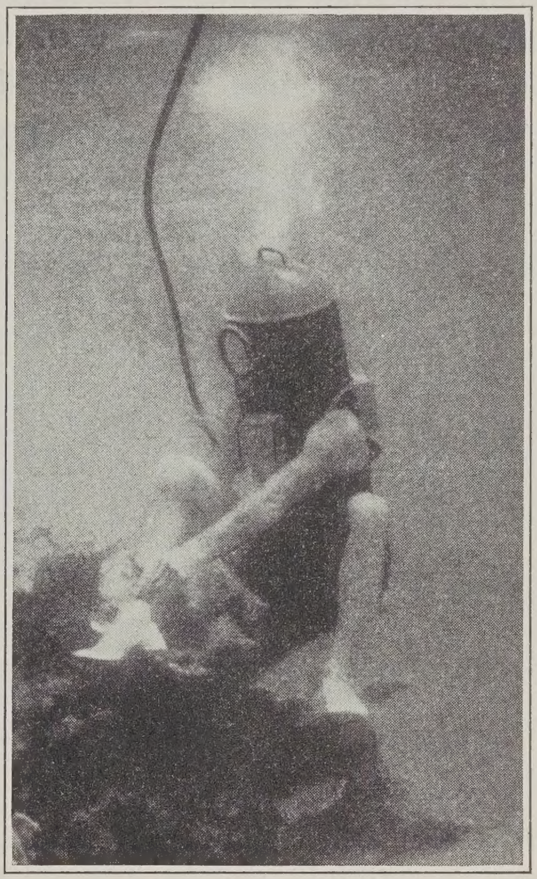


Photo by Miller Dunn Co.

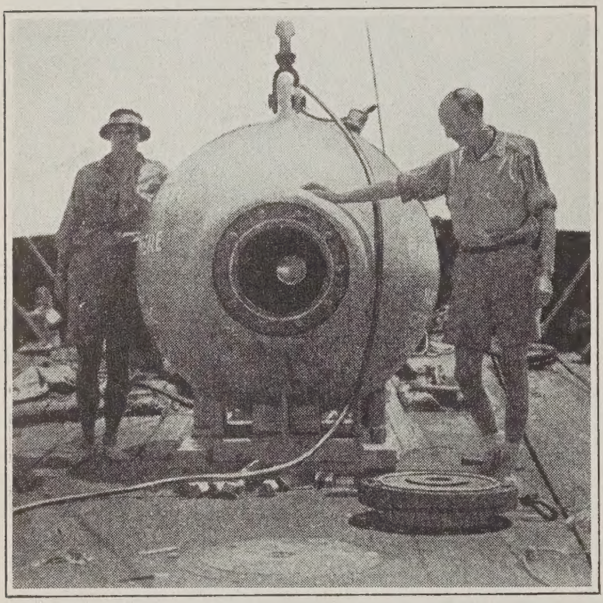
FIG. 4. Photographed off the Florida coast. What information can the biologist obtain by underwater trips?

The sunlight filters through this clear tropical water and flashes from the brilliant reds and yellows of the fish. The beauty of the ocean floor with its brightly colored animals will delight you as it has the biologists who have gone down many times to study this active world of living things. They have described its beauties, artists have painted its scenes, and the camera has caught the graceful forms so that everyone may now enjoy the gardens undersea.

Until recently, undersea life was seen through panes of glass in the bottom of a small boat; diving in the helmet is a new achievement. Now that it has been perfected almost anyone can do it.

William Beebe was the first to make extensive use of this method of exploring the world of water forms. But he soon found the zinc pad and lead pencil too slow. A telephone now connects the observer with an assistant in the boat who takes notes as reports come up from below. The boat follows slowly as the biologist walks from place to place, now describing the giant jellyfish that is drifting past him, and then telling about the shark that noses about to investigate this queer creature with the enormous head.

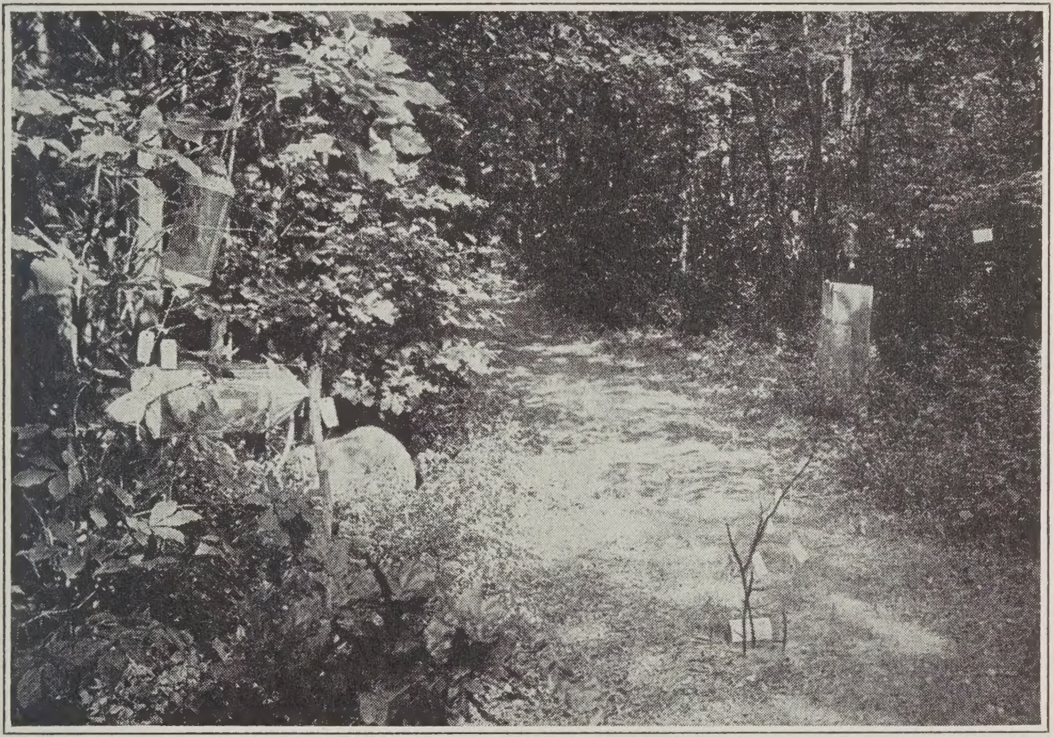
Not content with the study of the surface layers of the sea, Beebe and Otis Barton have descended to the astounding depth of half a mile. To do this they have used the bathysphere, a ball of steel with thick glass windows. With a powerful electric light casting a beam out into the surrounding blackness, the two men have seen things never seen before; they have been able to report adventures in a strange new world.



Courtesy William Beebe

FIG. 5. Barton and Beebe with the bathysphere. When the door has been bolted on, the two observers must remain cramped in a sitting position. Chemicals keep the air pure.

Long before these methods of studying the life of the sea had been developed, other devices were in use. Nets made of steel had been dragged on the bottom of the sea, sometimes as much as three miles down, and then hauled to the surface so that biologists might study the catch. Nets had been invented that could be dragged through the water at certain depths and closed before they were pulled in. In this way biologists could study the living things at different levels and could say that a certain fish lives at depths of half a mile but does not come closer to the surface nor go much farther down. Dredges with steel jaws had been dropped to the bottom and closed so that samples of the sand and ooze (mud) could be examined. This disclosed the fact that thousands of square miles of the ocean bottom are the graveyard of tiny animals whose skeletons sank after death. A single animal is too small to be seen by the naked eye yet the countless millions that have died have heaped up thick deposits of this ooze. Slowly the labors of many men are making it possible for biologists to describe life in the everlasting darkness of the ocean depths.

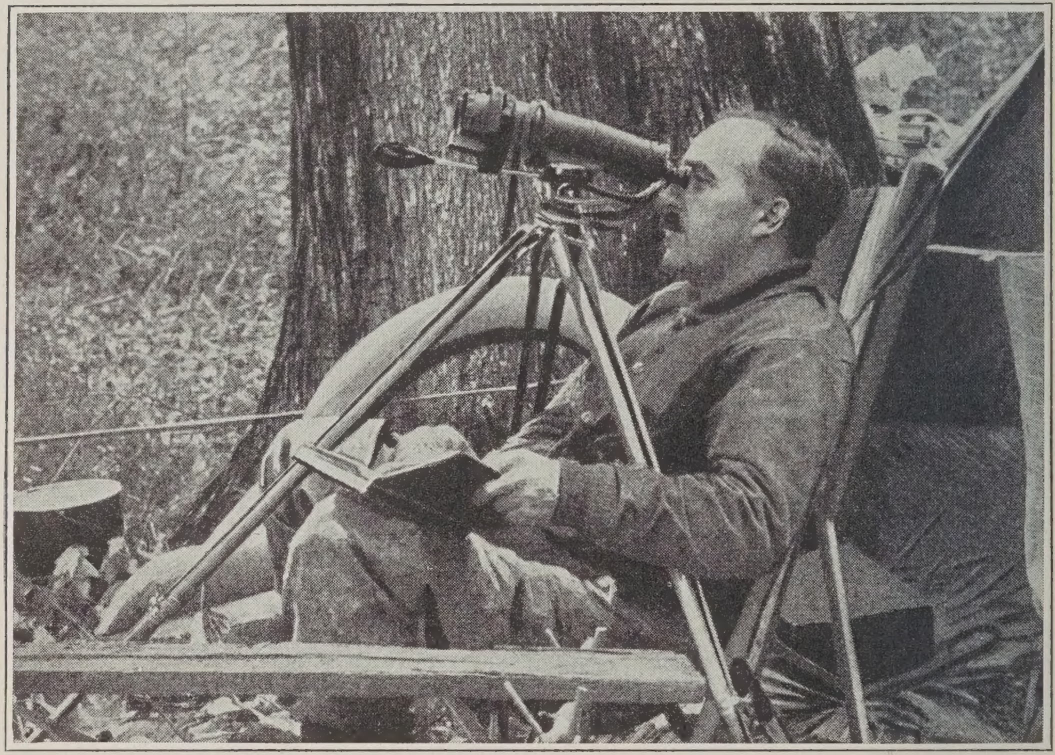


Courtesy American Museum of Natural History

FIG. 6. An outdoor museum. Part of the Nature Trail at Tuxedo, N. Y. How many exhibits are there? Could you build a simple nature trail?

The stay-at-home observer. Not all biologists interested in getting acquainted with plants and animals have wandered to the far corners of the earth to discover and describe them. Many have remained at home, knowing that patient observation is just as valuable in France or Great Britain or the United States as in Madagascar or the Galápagos Islands.

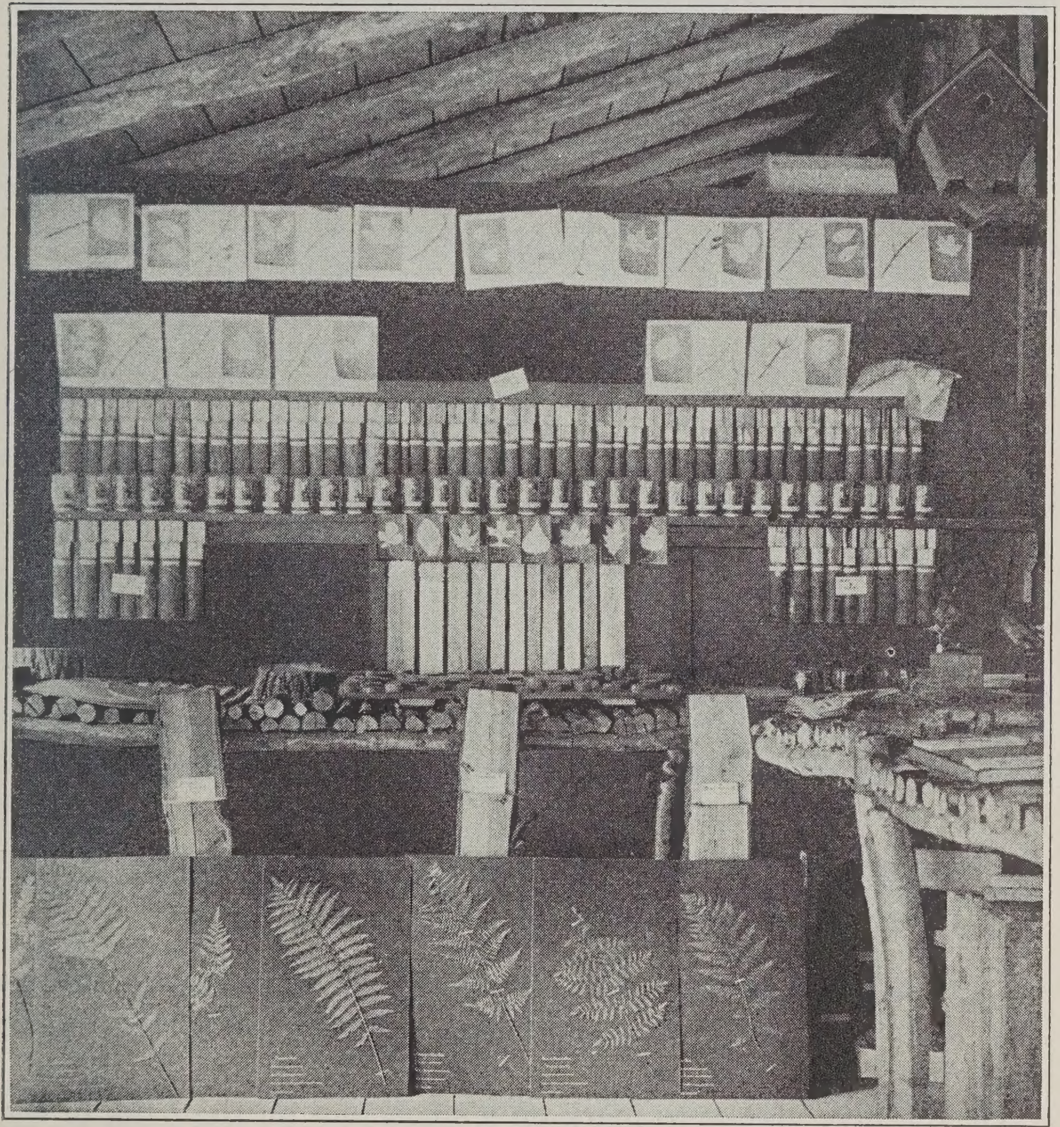
One of the most famous of the stay-at-home observers was Jean Henri Fabre. For most of the years of his long and useful life Fabre watched the insects in his garden and in the sunny fields. He would crouch, motionless, for long hours at a stretch, with his eyes fastened to the ground. It was by such patient observation that he saw the insect hunt food and store it, fight enemies, and mate. He saw how eggs were laid and how they hatched. Then he wrote down exact descriptions of what he had seen. He has left many simple and interesting accounts of his observations; most of them have been translated from the French so that you can read them. Sometimes he performed simple experiments with the insects he was studying. He had long noticed the march of some caterpillars which followed a leader in single file. To find out what would happen if their march did not bring them to food, Fabre led them to the edge of a bowl. There they continued their march around and around, following their leader.



Courtesy Professor A. A. Allen

Fig. 7. Professor A. A. Allen studying the ivory-billed woodpecker in a Louisiana swamp. Can you explain the uses of each of the objects in the picture?

Other stay-at-home observers may study birds, carefully noting their movements, the way nests are built, and how young are raised. This requires patience and keen powers of observation, too. And it requires much skill and cleverness because birds are equipped with such keen eyesight and are so shy that few of them will carry on the ordinary business of life if an observer is about. It is customary, therefore, to build a "blind," usually a small, tentlike structure of green cloth, designed to blend with the nearby plants. It must be put up at times when the bird will not be disturbed. When it has stood long enough for the birds to have become accustomed to it, the observer enters before dawn and remains for hours, eyes near a small peephole, notebook and pencil in hand, and camera within reach.



Courtesy American Museum of Natural History

FIG. 8. A corner of the Boy Scout Museum at Bear Mountain, N. Y. What suggestions for hobbies does this picture give you?

There have been many stay-at-home observers. Some have delighted in the study of frogs and toads; others have found snakes the most interesting of all creatures. Each has satisfied his love of the out of doors and added to the store of biological knowledge.

Backyard exploration. Equipped with a pad and a pencil, you too can start on a tour of exploration. You may fill notebooks with your observations of the wild life in a park, in a field, or in a city lot. You can collect specimens and lay out a museum of your own.

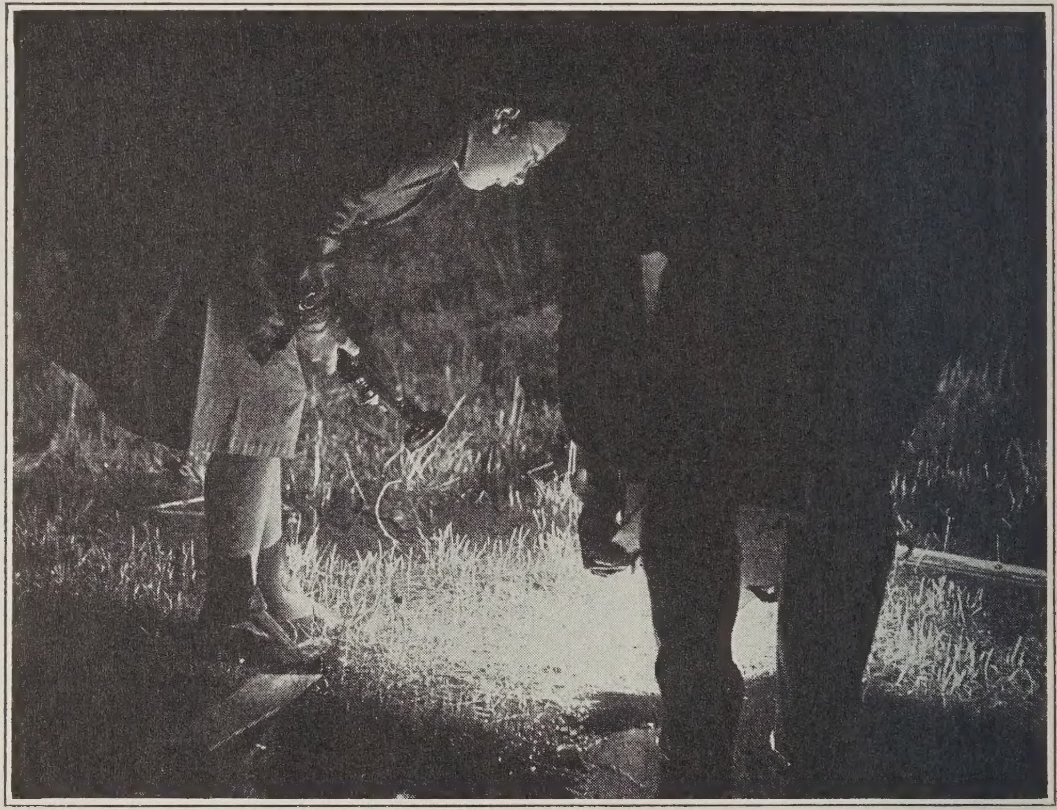


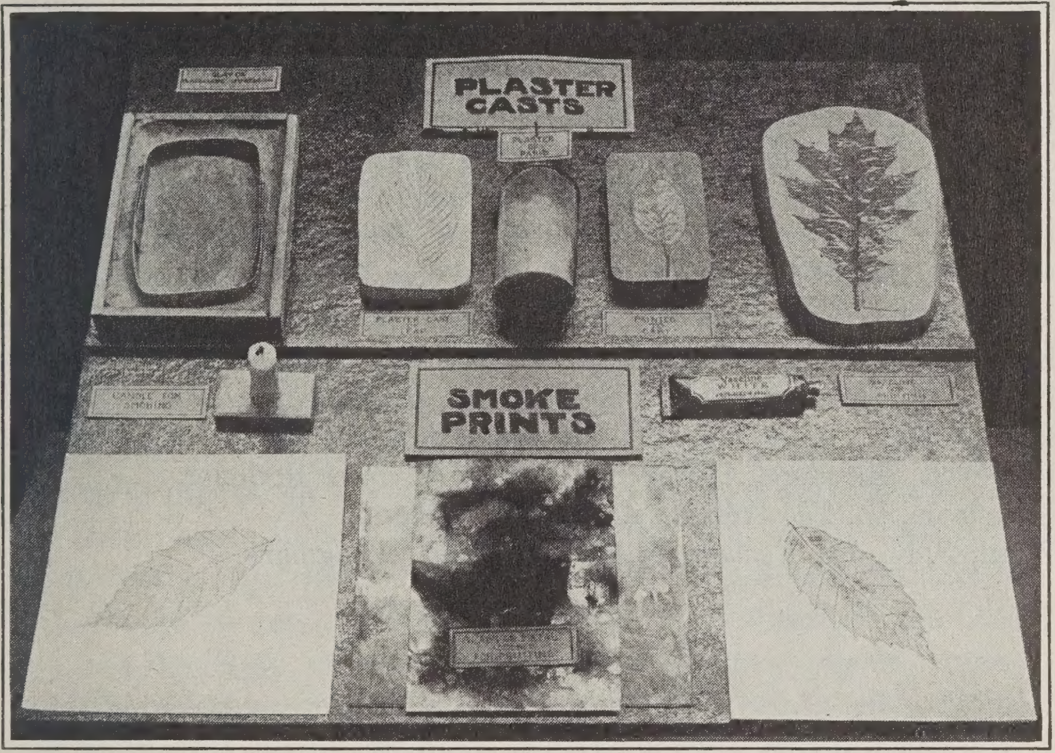
Photo by Frank Gehr

FIG. 9. The nature photographer is snapping a spring peeper (frog) in a swamp at night while a young assistant holds the flashlights. If you have a camera, you can build a photoflash bulb attachment yourself.

Or you may choose to mark off a small plot on the bank of the creek flowing by your house, the edge of a nearby wood, or a city yard. If you study this with care you will be amazed at the many *organisms* you will find. (An organism is a single living thing, plant or animal.) One biologist collected several hundred different kinds of insects from his own small backyard during a period of three years.

Your backyard may be a roof or a window sill. A sheltered board regularly supplied with bread crumbs will bring the passing birds to your sill. A piece of sod brought in from out of doors and watered carefully will grow into a miniature jungle. There will be much for you to observe; there will be many experiments for you to try.

In recent years, a new turn to backyard exploration has been given by camera enthusiasts. The camera can tell the most unusual tales in ways that are never forgotten or misunderstood. The beautiful curve of a leaf, the struggles of an ant dragging a fly twice its size, the beat of a hummingbird's wings may be caught and framed for the scrapbook.



Courtesy American Museum of Natural History

FIG. 10. This exhibit from the Nature Trail at Bear Mountain, N. Y., shows two methods of making leaf prints. How else might you prepare similar exhibits for your school museum?

In the next few chapters you will learn of the many kinds of animals and plants that are your neighbors on this earth.

Good Books to Read

Andrews, R. C., *Ends of the Earth.* Putnam. *On the Trail of Ancient Man.* Putnam.
Beebe, W., *The Arcturus Adventure.* Putnam. *Beneath Tropic Seas.* Putnam. *Galápagos.* Putnam. *Nonsuch: Land of Water.* Harcourt.
Cheesman, E., *Hunting Insects in the South Seas.* R. O. Ballou.
Comstock, A. B., *Handbook of Nature Study.* Comstock.
Darwin, C. A., *A Naturalist's Voyage around the World.* Oxford Univ. Press.
Denslow, C., *Making Nature Collections.* Boy Scouts.
Ditmars, R. L., *Thrills of a Naturalist's Quest.* Macmillan.
Downing, E. R., *Our Living World.* Longmans.
Hedin, S. A., *Across the Gobi Desert.* Dutton.
Hornaday, W. T., *Campfires in the Canadian Rockies.* Scribner.
Mann, P. B. and Hastings, G. T., *Out of Doors.* Holt.
Miller, L. E., *In the Wilds of South America.* Scribner.
Mills, E. A., *Adventures of a Nature Guide.* Doubleday Doran.
Nesbit, W., *How to Hunt with the Camera.* Dutton.
Peattie, D. C., *Green Laurels.* Simon and Schuster.
Roosevelt, Theodore, *African Game Trails* (2 vol.). Scribner.
Stefansson, V., *The Friendly Arctic.* Macmillan.
Ward, F. K., *The Romance of Plant Hunting.* Longmans.

CHAPTER I

THE SORTING OF ANIMALS AND PLANTS

The variety of living things. The variety of living things on this earth must always remain astonishing to anyone who thinks about it. You have probably thought of the city streets as empty of living things, except for men, women, and children. But everywhere you may see dogs of many breeds, cats, horses, various kinds of birds; and in summer insects, such as flies, mosquitoes, an occasional butterfly, and so on. Indoors you may find other kinds of birds and insects and in your biology room there will undoubtedly be snakes, turtles, white mice, and fish. And plants have not yet been mentioned.

Even in a city you see grasses, many kinds of trees, and smaller flowering plants such as dandelions in the lawn and geraniums in the classroom; there may be ferns on the window sills and water plants in the aquarium. This list could be lengthened considerably if you were to add the plants you find in the market, the plants you eat as fruit or vegetables — the oranges, apples, lemons, peaches, potatoes, carrots, beans of all kinds, tomatoes, cabbages, and so on. Of course, during a day in the country you could add a large number of plant and animal forms even though you are not a professional biologist.

Preparing lists of animals and plants becomes too complicated when you remember that the tropics have their own special kinds of living things, that the desert holds plants and animals very different from those you see about you, and that even the icy arctic and antarctic regions support large numbers of plants and animals of various types.

Actually, more than one million different kinds of living things have been named by biologists.

The need for classifying. Picture to yourself a museum in which the many specimens of different kinds of plants and animals were placed in cases in the order in which they arrived. It would be very difficult to find any particular living thing which you might wish to study. At one moment you might be examining a lion, at the next moment a rosebush. Hours later you might find a case containing a tiger. Would it not have been easier had the tiger been put beside the lion?

Whenever anyone wants to keep track of large numbers of objects he puts similar ones together; that is, he *classifies* them. The more objects one has, the more need there is of some sort of grouping or sorting. The boy whose hobby is collecting stamps carefully puts all those of one country in one special section of his book. In this way he finds it much easier to find a certain stamp and to remember what is in his collection.

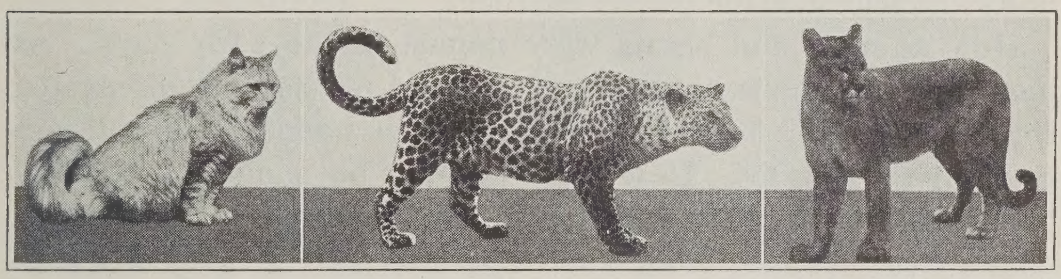
How all kinds of objects can be classified. You saw that in a stamp collection certain ones are put together because they are alike in one easily recognizable way: they were printed in the same country. There is a name for these ways in which things are alike or different. It is *characteristic.* The characteristic used in classifying the stamps, therefore, is the name of the country which produced them. Coins, too, may be classified according to the country in which they were produced, as English, German, United States coins, and so on.

But if you have large numbers of coins to take care of you do not stop when you have grouped them according to their countries. You find that the United States coins are not all alike. Some may be pennies, some nickels, and some dimes. So you group them according to their value. In other words, you now make a further subdivision by using another characteristic; in this case the value of the coin.

Now, having got together all your United States coins, and then separated or subdivided them into nickels, pennies, and so on, you can go still further in your classification. You can subdivide the pennies, for example, according to the date of issue; with this as a basis you can separate the pennies into still more groups.

You can readily see that the first time you arrange your objects in groups, each group is a large one; it contains many individuals. Every time you subdivide it, the groups which are formed become smaller and smaller. If you have 500 coins altogether, the United States coins may form a group of only 100. When you have subdivided these according to value, you may have only about 30 in each subdivision; let us say, 35 pennies. And by the time you make a group of United States pennies coined in 1880 you may have only one or two such specimens; the group is very small. This is true of all classification.

It is interesting to note that the larger the group the smaller the number of characteristics in which the objects are alike; the smaller the group the more characteristics do the individuals have in common. All the coins, making up the largest group, were alike only in that they were coins. The next subdivision contained objects that were alike in two characteristics; they were coins and they were American. The next group was still smaller; it was composed of objects that were coins, American, and pennies. And the last group, the smallest, contained objects which were coins, American, pennies, and issued in 1880.



Courtesy National Zoological Park

FIG. 11. The Persian cat, the leopard, and the puma are placed in the same genus because of their great similarity. What are the differences?

The classification of plants and animals. You may have noticed above that in order to classify objects you must study them closely and know a great deal about them. With stamps and coins that is relatively easy, but when it comes to animals and plants the problem is much more difficult. More than two thousand years ago the great Greek scientist and philosopher, Aristotle, examined and dissected animals and wrote detailed and accurate descriptions of many of them. In doing this he came to recognize that certain animals had similar characteristics. He arranged them in large groups such as the mammals, birds, reptiles, fishes, insects, and some others.

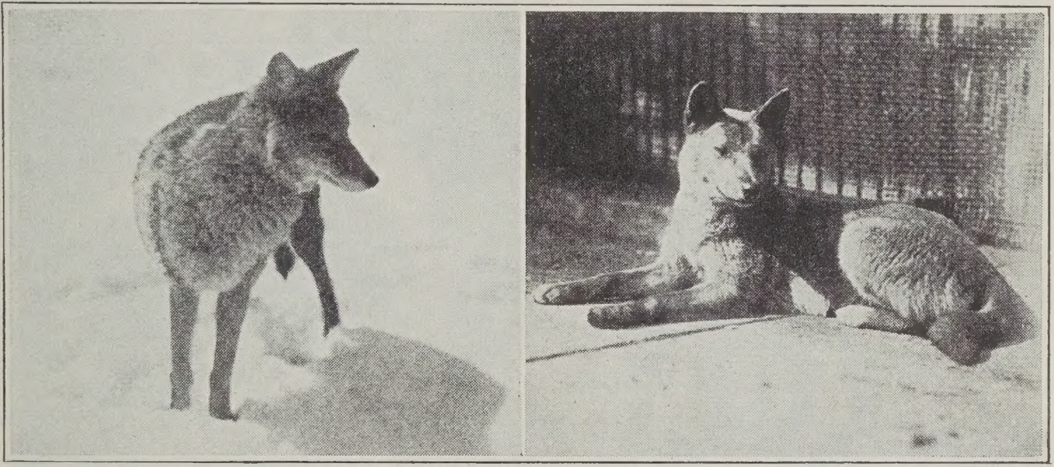
But as biologists continued their studies they found that they were continually obliged to change the classification because new facts were discovered about the animals and plants then known. And there was further need for improving it as the number of living things collected by men in many different parts of the world grew larger and larger. The simple systems of classification originally used were no longer satisfactory.

Just as with a large coin collection it becomes necessary to make more and more subdivisions by selecting different distinguishing characteristics, so with plants and animals the first large groups had to be subdivided again and again. Of course, this was not all done at one time nor by one man; many contributed. But a more complete scheme than had appeared before was developed and established by Carolus Linnaeus. He seems to have had a passion for collecting and classifying, so he set himself to work on the classification of plants and animals which had been suggested in large part by earlier scientists. But before he got very far he realized another difficulty. He could not classify living things unless he had suitable names for them.

How animals and plants were named in the early days. As more and more new kinds of animals and plants were discovered throughout the centuries, the problem of naming living things grew more difficult. How were they to be named so that all biologists would know which form was referred to? Common names were useless. They had been developed without any plan so that the same animal went by different names in different parts of the country. And sometimes the same name was applied to very different animals. For example, the common name "gopher" is used for several kinds of ground squirrels in the western part of this country, for a tortoise in the far south, and for a snake in the southwest. In the early days of biological classification, to avoid this confusion, whenever anyone wanted to refer to an animal or plant he was obliged to write a full description of it. This description served as a name which other scientists could recognize, but the more men learned about an animal or plant, the longer became its name. Sometimes it was four or five lines long! Evidently this could not go on; shorter names were needed but names that everyone would recognize.

Linnaeus's scheme for naming animals and plants. It remained for Linnaeus to perfect a system by which the organism could be described fairly well and yet have a short name. In an improved form this biological language is still used because of its great simplicity. Let us see how it works.

Certain animals such as cats, lions, tigers, and leopards are plainly much alike, so Linnaeus grouped them together. In the same way he grouped together dogs, wolves, and coyotes. A group of this kind he called a *genus* (jee′nus). The plural is *genera* (jen′-er-a). And the special kind of animal within the genus, such as the cat, the lion, or the tiger, he called a *species* (spee′shees). Having grouped them together in this way, he was obliged next to find names for every genus. In those days every educated person knew Latin, so Linnaeus used only Latin words. He found a Latin word to describe each genus. For instance, he called the group or genus which includes the cat, lion, tiger, *Felis* (fee′lis). Notice the capital letter. The genus which includes the dogs and wolves he called *Canis* (can′is). Each kind of animal was then given two names; first the Latin word chosen for the genus and another Latin word to describe the species. For example, the cat received the name *Felis domestica.* The dog was called *Canis familiaris.*



Courtesy New York Zoological Society

FIG. 12. The coyote (*C. latrans*) and the dingo (*Canis dingo*) belong to the same genus. What characteristics have they in common to distinguish them from the cat (*F. domestica*)?

In time he placed all plants and animals in little groups of this kind, or genera, and gave them all such double names. Of course, later biologists who had an opportunity to study plants and animals more carefully sometimes found that Linnaeus had made mistakes. They were obliged to change the original grouping of some animals and plants and thus to change their names. But, on the whole, Linnaeus's names have remained and his system of naming is the only one in common use. You can see that there are great advantages in it. If you heard for the first time about an Australian dingo you would have no idea how the animal looked. But if you were told that its name was *Canis dingo* you would at once know a great deal about it. You would not need a long description.

Linnaeus's scheme of classification. Linnaeus had grouped animals and plants into thousands of small genera and had named them. But no one could keep track of such large numbers of different genera. It was necessary to reduce the number of groups by putting together the genera that had many similar characteristics. That was done. The genus which contains the wolf, dog, coyote, and dingo is similar in many respects to the genus which contains the foxes. Such similar genera are now put together in a larger group known as a *family*. A study of the pictures will show the resemblance between these two genera, and the reason for including them in one family. Certainly these animals resemble one another more closely than the members of the dog genus resemble the members of the cat genus.

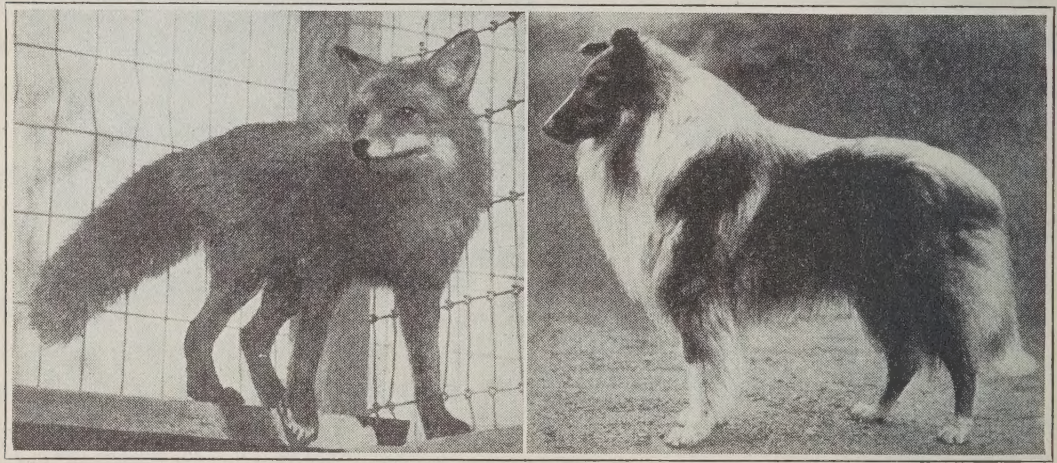


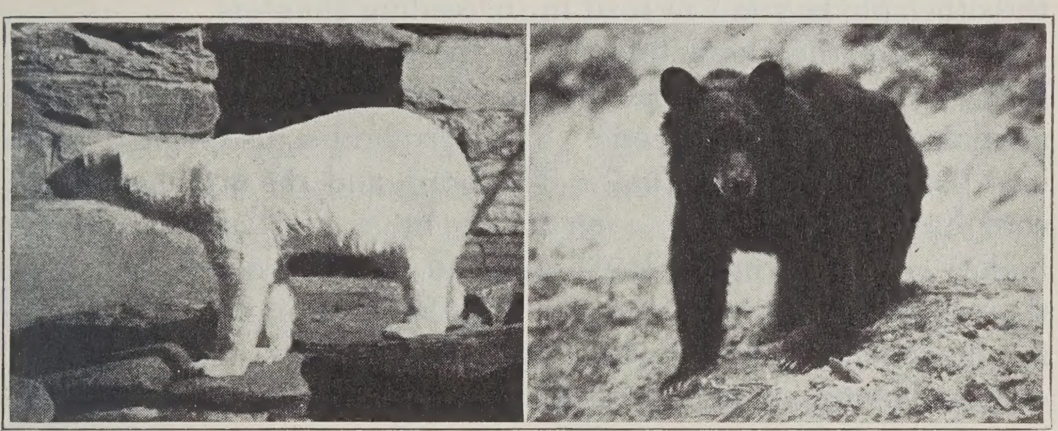
Photo by Hugh Davis *Courtesy U. S. Bureau Animal Industry*

FIG. 13. The red fox belongs to the genus *Vulpes* and the collie to *Canis*. These two genera are put into one family.

Further study showed that some families resemble one another much more closely than do other families. For that reason certain families are placed together in a larger group called an *order*.

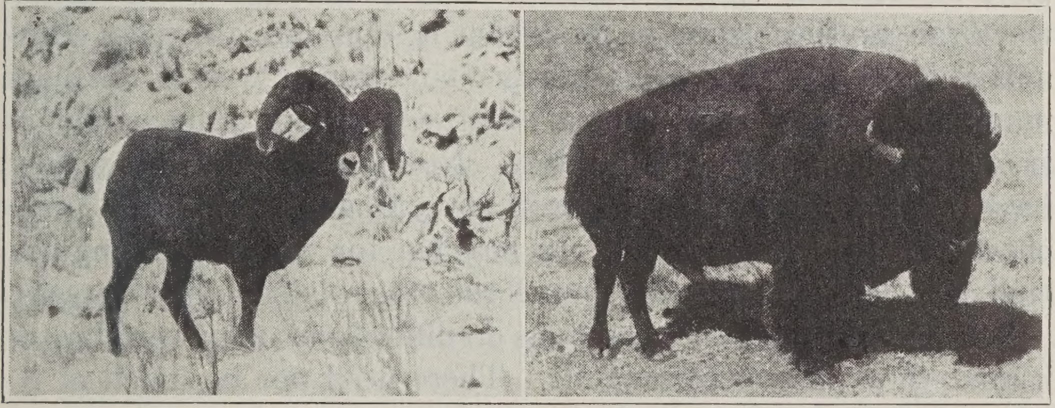
But biologists go further in their classification. Similar orders are grouped in the same *class;* like classes in a *phylum* (fy'lum); like phyla in a *kingdom*. There are only two kingdoms. You have always known them: the plant kingdom and the animal kingdom.

How Linnaeus's scheme works. Suppose you wanted to classify some animal with which you are well acquainted, such as man himself. You proceed by the same method that is used for stamps or coins. You begin by putting man in the largest group, the animal kingdom, and then trace him down to smaller and smaller groups until you have placed him in the proper species. That is, you must keep in mind that the kingdom is composed of phyla, the phyla of classes, the classes of orders, the orders of families, the families of genera, and the genera of species.



Courtesy National Zoological Park *Courtesy National Parks, Canada*

FIG. 14. The polar bear and the black bear belong to one family, different from the family which includes dogs and foxes. But since the members of these two families have much in common, they are put into one order (Carnivora).



Courtesy Northern Pacific Railway *Courtesy U. S. Forest Service*

FIG. 15. Compare this mountain sheep with the bison. What have they in common? They belong to different genera but to the same family. They are so unlike the Carnivora that they are put into a different order (Ungulata).

Man belongs to the phylum Vertebrata (ver-te-bray′ta).* Some biologists divide the animal kingdom into eleven phyla, others into as many as fifteen. Of course, man can belong to only one of these phyla. You will read about that phylum now. Of the other phyla you will read in succeeding chapters.

What are the characteristics of the animals classed as Vertebrata? They all have backbones, while the other phyla include animals without a backbone. The vertebrates also have a brain in a boxlike skull (*cranium*). The brain and the attached spinal cord are hollow. (Yes, even man's brain and spinal cord are hollow.) Furthermore, the brain and cord lie nearer the back than does the digestive system. All this is true of man. Therefore he belongs to the phylum Vertebrata.

Man belongs to the class Mammalia (mam-may′lee-a). The many kinds of vertebrates differ so much from one another that they have been divided into five different classes: the mammals, the birds, the reptiles, the froglike animals, and the fishes. Again man can be included in only one, the *mammals.* Naturally, all the members of the class Mammalia must have a backbone, a hollow brain, and so on. Every animal belonging to the phylum Vertebrata has these characteristics. However, all the mammals have in common further characteristics which are not shared by the birds, reptiles, frogs, or fish; that is, there are also class characteristics. It would not do to say that the members of the class mammals are warm-blooded and breathe by means of lungs; this is true but it is equally true of birds. Nor would it do to say they have four legs, for this is also true of many frogs and reptiles. These characteristics do not make it possible for you to distinguish (tell) the class of mammals from all the other classes of vertebrates.

The way in which the mammals do differ from other vertebrates is that they possess hair or fur. There need not be much of it. There is little hair on an elephant's body; there is even less on a whale's. But every animal with hair has been included in the class Mammalia. They have a second characteristic not found in animals of other classes; they have mammary or milk glands by which they feed their young. These young, in the case of almost all mammals, are born in a fairly well developed state.

---

* This is the older, more familiar term. Strictly speaking, the name is Chordata.

Man belongs to the order Primates (pry-may′tees). All the animals with fur or hair can be separated on the basis of other characteristics into smaller groups, the orders. You recently saw pictures of the order Carnivora (car-niv′o-ra) and the order which includes the bison (Ungulata); no doubt you are also familiar with the rodent order (rats, mice, and rabbits) and perhaps with others. Man belongs to none of these. The order in which man is placed is known as Primates. Its members are distinguished by their huge skulls (therefore a large brain), the type of hand they possess, their teeth, and so on. All the animals which display these characteristics, the monkeys, apes, and man, belong to this order. That is why you sometimes read the statement that the monkeys and apes are man's nearest relatives.

From order down to species. But men are so different from the apes and monkeys that, although all three belong to the same order, they are put into different families. Man belongs to the family Hominidae (hom-in′i-dee). Now most families can be subdivided into numerous genera but this particular family has only one genus, *Homo* (ho′mo). And the genus *Homo*, again, has only one living species, *sapiens* (say′pee-ens — meaning wise). Thus man's scientific name is *Homo sapiens*. All men belong to this species.

The single species "man." If there is only one species, man, it means that men as different from one another as the Negro, the white man, the Chinese, and the American Indian must all belong to the same species. That may surprise you. You may think that among wild animals biologists make separate species of forms that are really very similar while in the case of man they seem to lump very different kinds together. Yet if you studied these wild animals closely and knew them as well as you know man you would often find equally striking differences between the members of one species. Different forms of the same species * are called *varieties* or *races*. You will read more about the races of man in Part 3.

How you fit into the animal kingdom. You now know your scientific name and have narrowed down man's place in the world of living things. You knew you were an animal. What kind of animal? A vertebrate. What kind of vertebrate? A mammal.

---

* There is no simple satisfactory definition of the term "species." You will learn in Part 3 why this is so.

What kind of mammal? A primate. What kind of primate? A member of the family Hominidae. To what genus do you belong? To the genus *Homo*. To what species? To the species *sapiens*. To what variety or race do you belong? That question must be answered separately for each one of you, depending on what you are.

The plant and animal kingdoms. In the same way every other kind of animal and every kind of plant can be classified. To do this for just a few would take an enormous amount of time for anyone who is not trained in this work. To do it for all would be impossible for one person. But as you widen your acquaintance with living things you will find it convenient to know at least the larger subdivisions of the plant and animal kingdoms. If you know a little about classification it helps you to become better acquainted with living things and to remember new forms.

Pupil Activities

1. Test your acquaintance with animal life by the following method. Make a list of all the animals you know whose names begin with *a*; then list those whose names begin with *b*, etc. How long a list do you arrive at? There are actually about 800,000 different species of animals.

2. Why do not stamp collectors classify their stamps according to color?

3. Choose some group of common objects, such as automobiles (or use boats or houses), and prepare a list of characteristics by which you could subdivide them into groups and smaller groups.

4. All schools classify pupils so that they may be sent to the proper grades, classes, and rooms. List the characteristics by which your school classifies you. Be sure to take into account every item in your school program. Can you think of other characteristics that your school might have used? Which makes the better classification?

5. It would be interesting to find out something about Linnaeus, a man who could bring order and system into the plant and animal kingdoms. Look up his life and report. Try to make him as living a person as De Kruif makes Leeuwenhoek. (See Singer, C., *The Story of Living Things*, or Peattie, D. C., *Green Laurels*.)

6. The horse and the donkey belong to different species of the same genus. From your own observation of these animals, can you state which characteristics distinguish the one species from the other?

7. If there is a museum, zoological park, or aquarium in your city, visit it. List the most interesting animals that you become acquainted with on your visit. Can you state the large groups to which they belong?

8. Study the figures that show examples of the dog genus (*Canis*). What characteristics have they in common? Study the figures of animals of the cat genus (*Felis*) and the genus *Bison*. What characteristics are possessed by these that are not possessed by the dog? Of course you can study only external characteristics.

9. Following is a list of articles of furniture: table, chair, sofa, bed, desk, bookcase, davenport, piano stool, bureau, and dresser. Add any others that you may think of. Classify these into genera according to use (rather than according to size, shape, or where they are found). How many groups or genera will you make? Compare with the answers of your classmates. If you study Latin, you may be interested in making up a double name (genus and species) for each piece of furniture, as Linnaeus did for organisms.

10. Look back to No. 9. Could you gather these genera into families? What characteristics did you use for putting them into the same family?

11. List in order all of the groups beginning with the kingdom and ending with the species. There are, let us say, eleven phyla in the animal kingdom. The number of classes to a phylum varies, depending on the particular phylum; assume an average of four. The number of orders varies; assume an average of eight. Assume an average of eight families to an order; eight genera to a family; five species to a genus. To what total would that bring the number of species? Your final estimate is much too small.

12. Have you ever used a "key" to find the name of some plant or animal? Ask your teacher for some simple key for identifying trees. Practice by first "keying out" trees whose names you already know, then try to identify a few trees whose names you do not know.

13. With some help in the beginning, you will find it interesting to learn how to construct a key. You might first make a key to "key down" one of twenty or thirty assorted books on your bookshelves. (*Hint.* The library uses a key.) Then collect leaves, shells, seeds, etc., and construct a key for each. Try it on someone else to see whether it works.

14. Could you prepare a key for keying down each member of your class? (*Hint.* How does the school classify pupils?)

15. *Summary.* Classify the dog as the text classifies man. Include the reasons for your classification but do not trouble to learn any new Latin names. If you can do this and if you know why men began to classify living things you understand Chapter I.

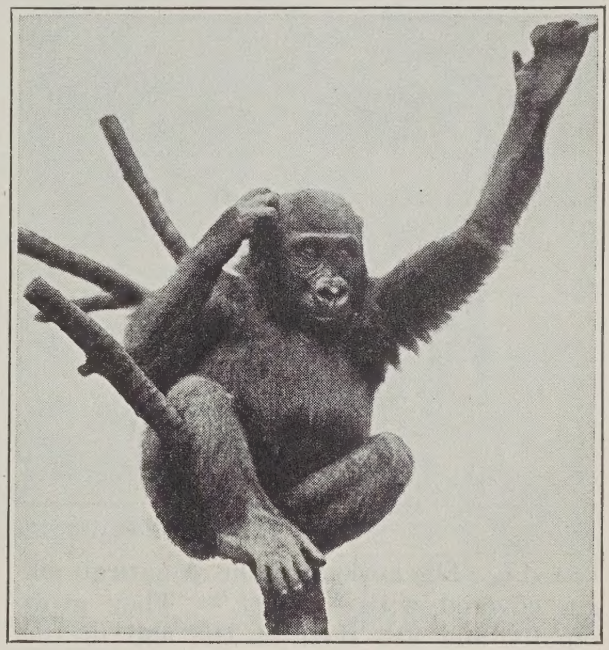
Good Books to Read

Hegner, R. S., *Parade of the Animal Kingdom.* Macmillan. *College Zoology.* Macmillan.
Locy, W. A., *Biology and Its Makers* (Linnaeus). Holt.
Pycraft, W. P., *The Standard Natural History, from Amoeba to Man.* Warne.
School Nature League, *Books for Nature Study.* School Nature League, N. Y. City.
Transeau, E. N., *General Botany.* World Book.

CHAPTER II

GETTING ACQUAINTED WITH MAMMALS

The apes — man's closest relatives. (*Order Primates.*) All mammals are somewhat like man in structure, but the great apes, such as the chimpanzee, the gorilla, and the orangutan, resemble man much more closely than do any other animals. Furthermore, scientists have performed many interesting experiments with apes and have discovered that they approach man more nearly than do other animals in their ability to learn and solve simple problems. Dr. Harry C. Raven of the American Museum of Natural History in his fascinating story about Meshie, his pet chimpanzee, tells how Meshie has learned to play with the children and to eat at the table.



Courtesy New York Zoological Society

FIG. 16. Why is this gorilla placed in the same order (Primates) as man?

Hoofed mammals. (*Order Ungulata.*) This is a large and varied order but all its members are plant eaters with grinding teeth. It includes such forms as the giraffe, the deer, and the buffalo; the zebra and the cow; the rhinoceros and the gazelle; the elephant and the goat. Most of these animals have a single or double hoof which makes them fast runners and sure-footed climbers. However, the elephant, the rhinoceros, and some others have several toes; their hoofs are more like nails. Like other vegetable feeders in the animal kingdom most of these animals are not ferocious. Few of the hoofed mammals attack other animals, but when attacked, some fight fiercely, using hoofs, horns, or tusks. Some, like the bison and reindeer, live in herds, seeking safety in numbers. Some, like most deer and antelope, resort to flight when danger threatens; they are well equipped for this with their long and slender legs.

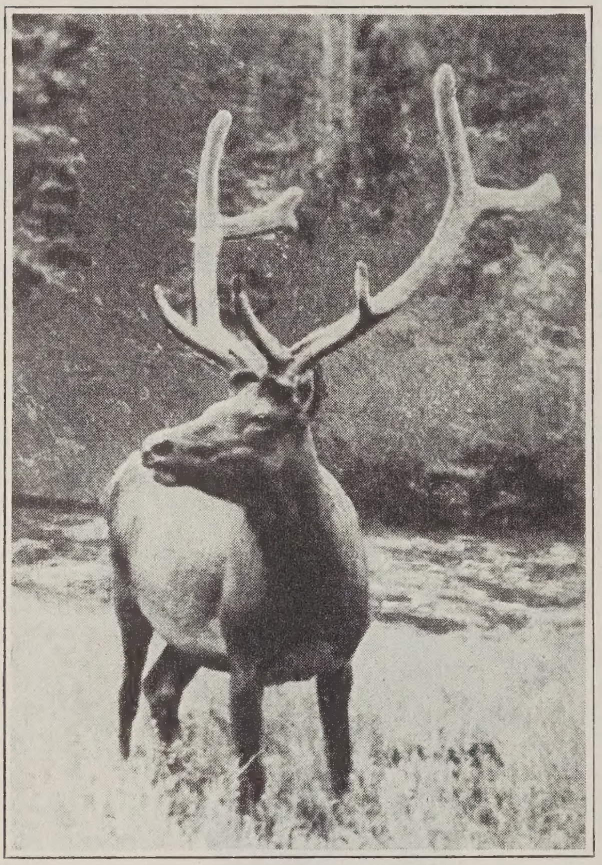


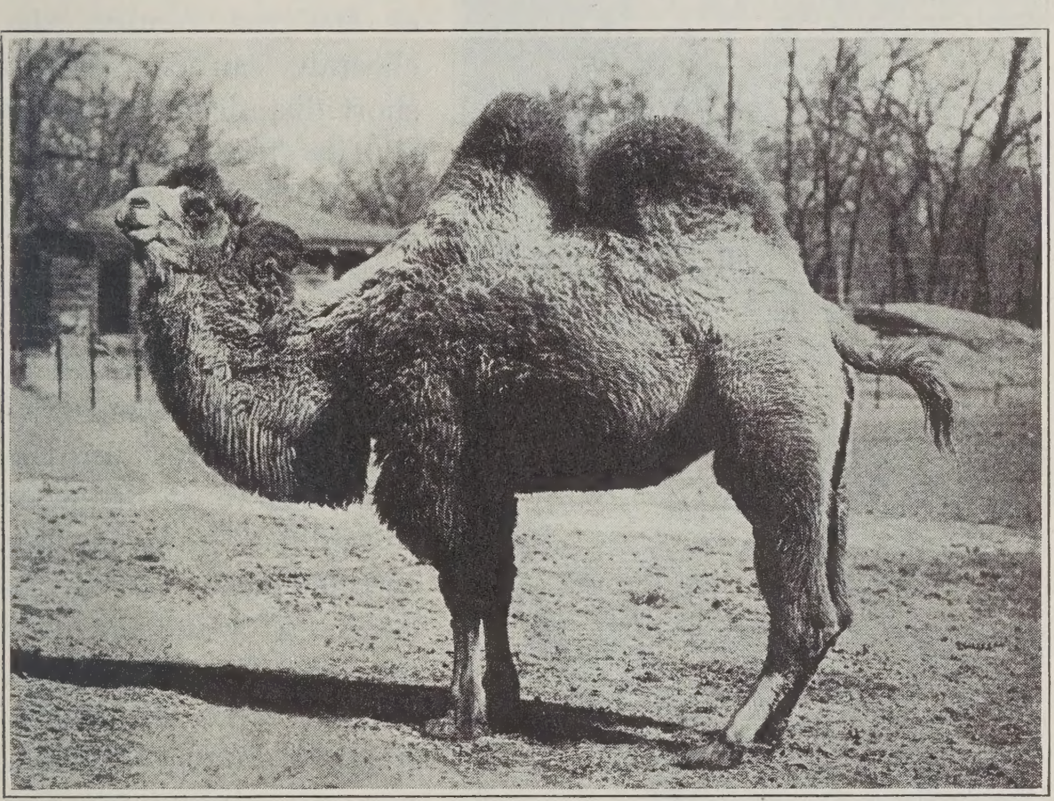
Photo by Selina T. Johnson

FIG. 17. The antlers of the American elk are covered with "velvet." They grow rapidly and are shed at the end of the season.

From the earliest times of which there is record man has domesticated the hoofed mammals. They are well fitted for this because they are generally obedient and they need little care, since they feed by grazing. In every part of the globe they are used as beasts of burden. Reindeer pull sleds in the arctic; oxen still do much hauling of loads in Sicily and elsewhere; the horse, the yak, and the donkey do their share in many countries. In India, the elephant is employed for much of the heavy work. It takes the place of a derrick, lifting huge logs with ease. It piles them up neatly, too, without direction, for the elephant is unusually intelligent and learns readily.

In the desert the camel is invaluable as a beast of burden; it can travel long distances without water and its hoofed toes spread, keeping the foot from sinking into the sand. The leader of a camel pack train, carefully selected for the position, can find its way unaided along the caravan routes when once it has been over the ground. Without landmarks it covers mile after mile of desert in a straight line to its destination. In South America, the llama takes the place of the camel. It, too, is covered with thick matted hair excellent for making lightweight, soft woolen cloth. Like its relatives of Asia and Africa it is surly and complaining, always lonely though living so close to man.

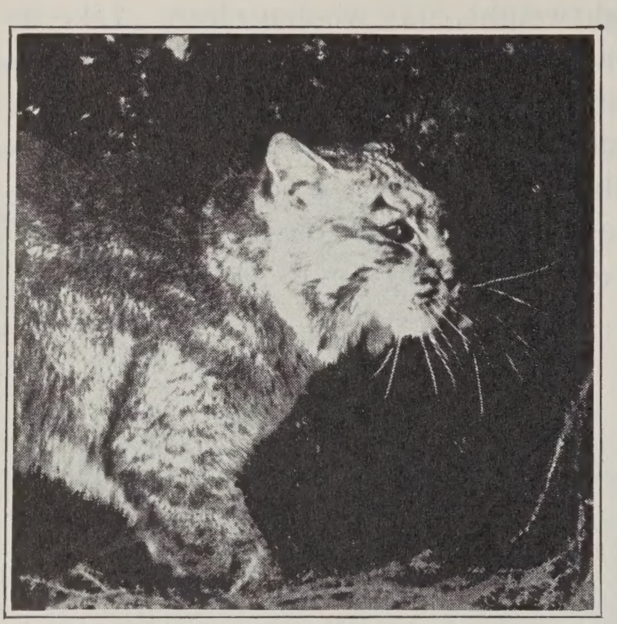
Meat eaters with cushioned feet. (*Order Carnivora.*) In contrast to the hoofed vegetable feeders are the *carnivores* (car′ni-vores) or meat eaters. Some of them, like the bears, do not live on meat alone. They relish berries of many kinds as well as small prey, such as ants and other insects. Some, like the hyena, depend on carrion (dead animals). But most of them, and perhaps those that are most interesting, hunt and kill. The wolves, coyotes, and foxes run down their prey. The wolf, which is outstanding neither in speed nor strength nor courage, sometimes hunts in groups or packs. The members of the cat family, however, depend on stealth and therefore usually hunt alone.



Courtesy New York Zoological Society

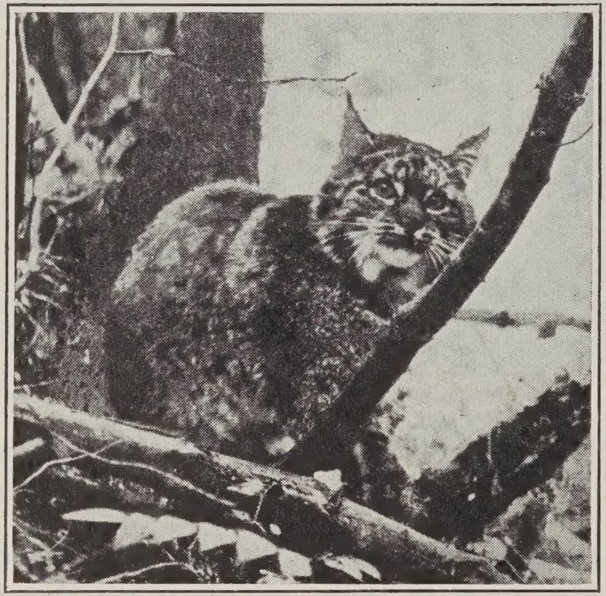
FIG. 18. The Bactrian camel is a native of Central Asia. You can tell it from the Arabian camel because it has two humps.

Many of the successful hunters of the cat tribe have coats which blend with their surroundings. The tawny lion inhabits sandy plains and rocky places; the striped tiger stalks his game among tall reeds and grasses. These animals must be sly and silent; they must see well in the dark; they must be powerful and exceedingly swift. It is said that one member of the cat family, the cheetah, can dash for a short distance at the rate of two miles a minute. The eyeteeth of carnivores are large and strong, for tearing flesh. The lions, tigers, and leopards have, besides, back teeth which are like sharp-edged scissors for cutting up the meat before it is swallowed. The rasping tongue picks the bones clean. If you have ever let a cat lick your hand you have felt its tongue, rough as a file. The long, curved claws can rip through the victim's hide. When not in use they are drawn back into pockets of skin.



Courtesy U. S. Bureau Biological Survey

a



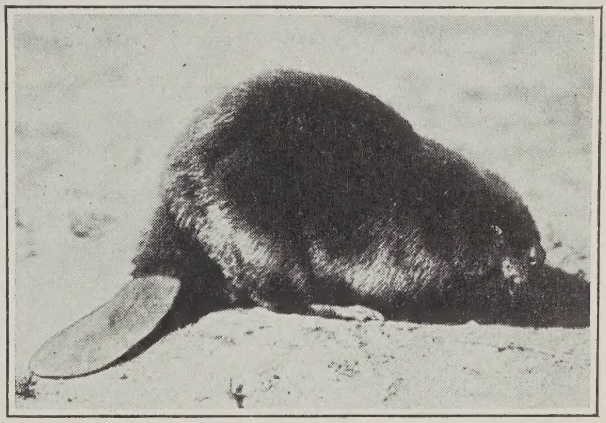
Courtesy National Park Service

b

Fig. 19. *a.* The Canada lynx or bobcat. This picture was taken in Oregon. *b.* The wildcat or catamount is smaller than the Canada lynx. Can you discover an easy way of telling them apart?

In the days of ancient Rome, when Pompey was able to show six hundred lions at a time, lions must have been far more numerous than now. In fact, in prehistoric times they probably spread over the greater portion of Europe as well as Asia and Africa. In our part of the world, this whole group is poorly represented. Of the cat family we have only the lynx, the wildcat, and the puma.

More common mammals. (*Order Rodentia.*) The gnawing mammals, or rodents, are familiar to all of you no matter where you live. There are about 2000 species spread over practically the whole globe and living in very different surroundings. They have learned to find food in the hot desert and in the arctic snow and ice. They burrow, live in trees, or in the water. You all know rabbits, rats, mice, squirrels, and woodchucks. In the western states the whistling marmots and the prairie dogs are equally familiar. Most rodents are timid and small and without means of defense. The two pairs of front teeth are well developed for chiseling and retain their power of growth. If a rodent has no opportunity to gnaw hard things and thus to wear these teeth down, they keep on growing just the same. They have been known to grow to four or five times their natural length and bend around in a circle until the animal could no longer feed itself.



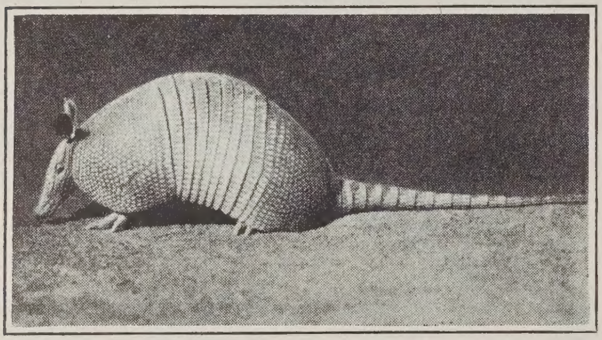
Courtesy National Parks, Canada

Fig. 20. The beaver has a large, flat, hairless tail. When frightened, a swimming beaver slaps the water with its tail as a warning to others.

A rodent of which you all know even if you have not been fortunate enough to meet one in the woods is the beaver. It was nearly killed off by men who wanted its valuable fur, but fortunately it is now protected in many states and is again multiplying rapidly. Now it is not an unfamiliar sight particularly at night to see one swimming swiftly and silently upstream, nostrils and eyes above water, its teeth hooked into a large log which it drags to its dam. It fells trees quickly and builds dams that are the envy of the engineer.

Moles and their relatives. (*Order Insectivora.*) An animal that is often confused with the rodents is the mole. It lacks the characteristic chisel-like teeth and feeds on insects and worms. Nearly blind and defenseless, it is fitted out with a pair of efficient shovels in the form of front legs. It can literally "make the dirt fly" as it digs its way through the soil. Its tunnels may extend for more than a hundred feet and since it digs just under the surface of the ground it can wreck your lawn if it decides to favor you with its presence. A mole is a tiny animal, usually not much larger than a mouse.

Closely related to it are the shrew, which looks like a tiny mouse except for its teeth, and the hedgehog. The hedgehog lives in Europe and must not be confused with the porcupine of this continent. Both possess sharp spines or quills but the hedgehog can do what the porcupine cannot do; when danger threatens it rolls itself into a ball with its head and feet neatly tucked away inside, and its spines sticking out in all directions.



Courtesy American Museum of Natural History

FIG. 21. The armadillo, when attacked, pulls in its legs and head and rolls up in a ball. Between the hard plates of its coat of mail are a few scattered hairs.

Unusual mammals. In contrast to the familiar rodents which are always alert and busy over something is the sloth. The sloth lives out its lazy life in the jungles along the Amazon River. Here it hangs body downward from the limbs of a tree, and when really forced to move, which happens rarely, it remains in this same position. Of course it also sleeps and eats hanging upside down. It does not go in search of food but feeds with its almost toothless jaws on the insects that come within its reach.

Related to the sloth is the armadillo (ar-ma-dil'lo) of South and Central America. The armadillo is also toothless, living on insects and decaying flesh. Slightly more active than the sloth, it burrows out a house for itself and at night comes up and walks about slowly, looking for food. It does not need speed to escape its enemies; it is protected by its armor.

The giant anteater of South America is toothless, too. With its strong claws it digs into an anthill, pushes in its long, narrow snout, darts out its ten-inch, slimy tongue, and laps up the ants it has brought to the surface.

Then there are the pouched mammals (*Order Marsupiala*), the kangaroos of Australia and opossums (oh-pos'sums) of our own country. The young are born when they are only one or two inches long and altogether helpless. To give them sufficient warmth and protection they are carried in a pouch in the mother's body. This pouch is like a pocket of skin. Here the young live for weeks until they are well enough developed to move about by themselves.

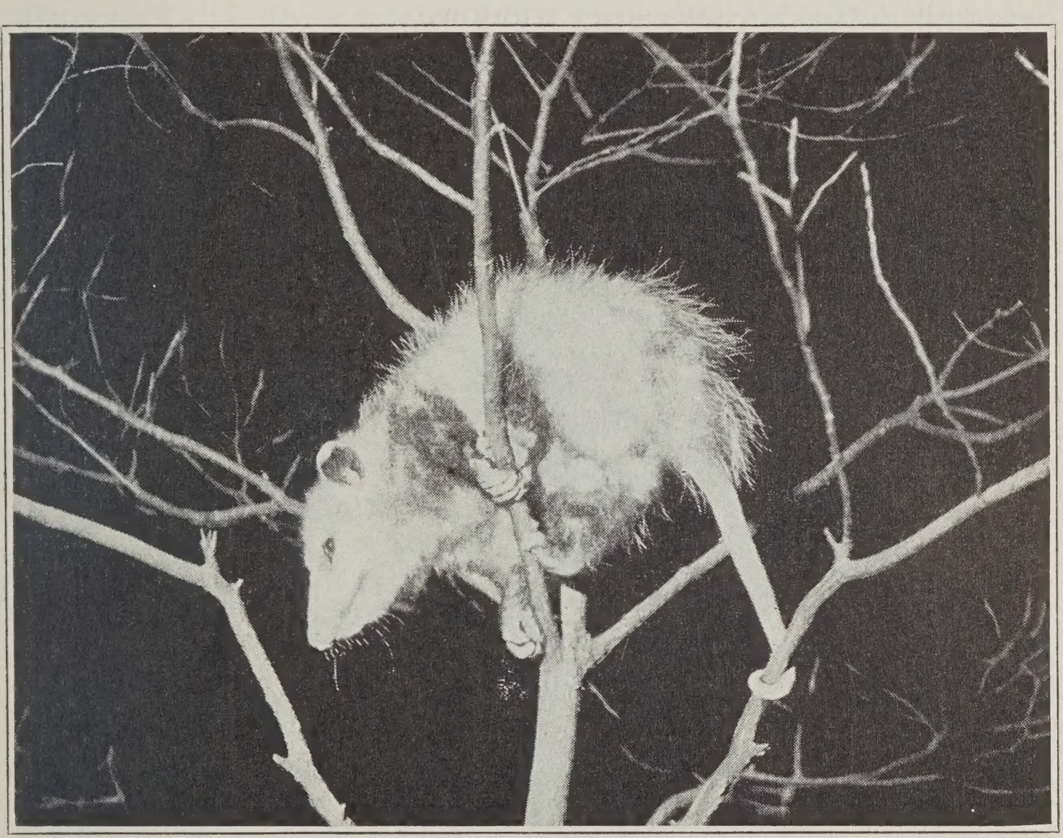
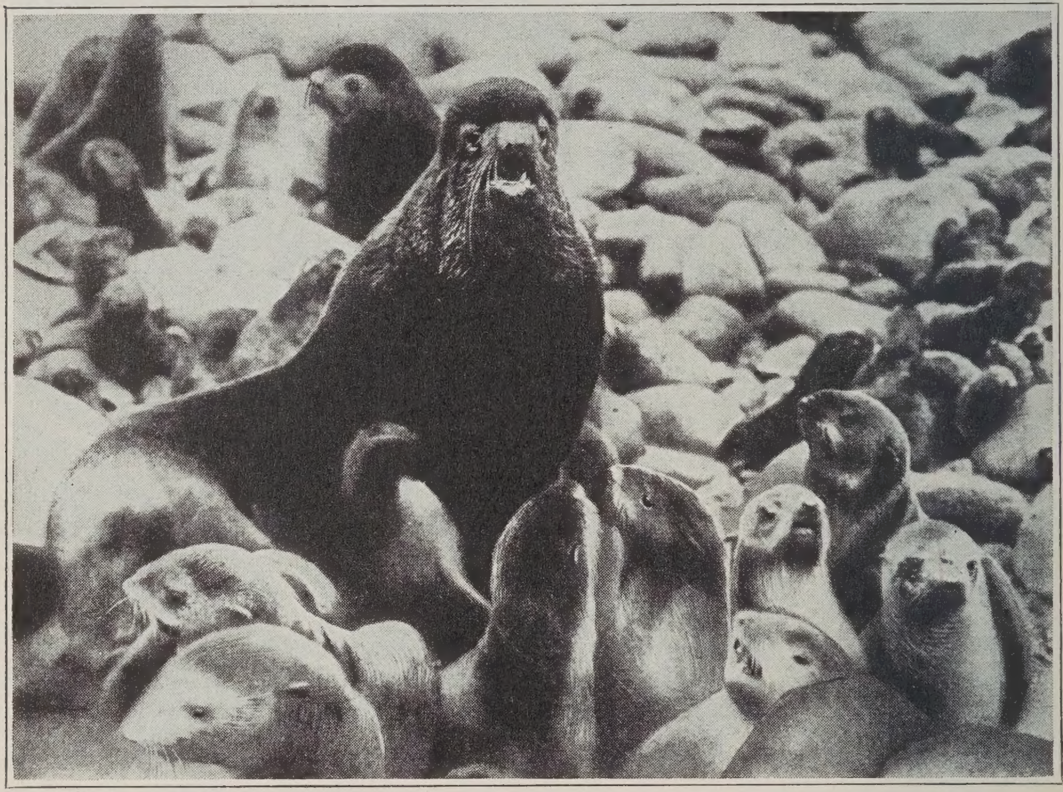


Photo by Frank Gehr

FIG. 22. The opossum is the only pouched mammal found outside of Australia.

But strangest of all mammals is the duckbill (*platypus*). It lays eggs much like a reptile, but since it feeds the young with milk and has a covering of fur it is considered a mammal. About the size of a muskrat, with webbed feet and a ducklike bill, it swims in the rivers of Australia and feeds on small water animals.

Mammals that live in the sea. A whale is so dependent on the water and so fishlike in its shape and general appearance that at first glance you might not classify it as a mammal. But closer examination discloses the two distinguishing characteristics: it has mammary (milk) glands and its skin, though mostly naked, has a few bristles of hair. The fact that it cannot live on land, has no hind legs, and has small flippers for front legs does not change its place in classification. Whales have always been interesting to man, no doubt because of their size. When the ancients described a whale as taking up in length and breadth more than two acres of ground, they were, of course, exaggerating. But a large whale, if it could stand up on its tail before a high building, could look right into a seventh story window.



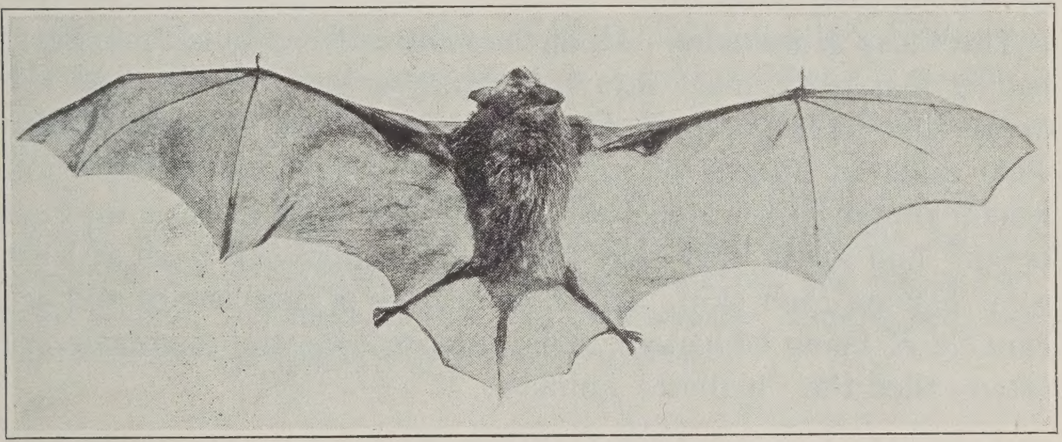
Courtesy Northern Pacific Railway

Fig. 23. The seal is equipped with sharp, pointed teeth like all other Carnivora.

Since they usually live in icy waters, these animals need large amounts of fat, called blubber, to protect them against the cold. This blubber can be turned into oil by man; a good-sized sperm whale may yield 150 barrels of sperm oil. Certain whales, too, have long been hunted for their whalebone. Plates of whalebone hang down like a curtain in the mouth. When the whale scoops up a mouthful of fish or even tiny plant and animal forms, it can expel the water through this curtain or sieve of whalebone and keep the solid particles as food.

Because it is so difficult to study the whale, there have been many fanciful stories told about these animals. A whale cannot swallow a man nor does it even attack man. And whales do not spout water. As a whale can stay under water half an hour at a time it must hold large quantities of air in its lungs. When at last it comes to the surface this air is breathed out. The water vapor in its breath condenses on a cold day (as does yours) into drops of water and it is this that is seen when the whale "spouts."

There are other mammals that live in the sea: the walrus, the seals, and the sea lions. But they are only distantly related to the whales; they belong to a different order. They spend part of their time on land and are much less fishlike in appearance. In fact, careful study of their structure shows that they closely resemble the Carnivora. Their legs are much shortened and are used as paddles so that on land these animals waddle awkwardly. But their teeth are much like those of a dog and in intelligence, as you know, they are not unlike the carnivores. Sea lions are easily trained for the circus.



Courtesy American Museum of Natural History

FIG. 24. This brown bat shows how the membranes attached to body and legs are stretched out by the long finger bones.

Mammals that fly. (*Order Chiroptera.*) A few mammals, such as the bats, can fly like birds and better than many birds, too. But of course they do not have feathers. They resemble a tailless mouse with big ears and large folds of skin under the arms to be used as wings. Their habits are unusual, too. All day long they hang head down hooked to the rafters of some building, or in a cave or hollow tree. Some species prefer to sleep thus in huge colonies of several thousands. Here they hang, constantly scolding and complaining as one after another, by changing its position, disturbs its neighbors. At dusk the group breaks up and each bat flies off alone in search of fruits. These bats are great feeders, eating more than their own weight daily. Other species of bats, however, live on insects. Their eyesight is so keen at night and their flight so sure and steady and noiseless that they can, and do, come exceedingly close to you without ever touching you. Because they come so close you may have the feeling that they will touch you. This no doubt was the beginning of the old superstition that they catch in your hair or harm you in some other way. Of course, they never do.

The *Class Mammalia*. All of the mammals, apes and monkeys, hoofed mammals, meat eaters, kangaroos, bats, whales, and the many that have not been mentioned (there are altogether some 4000 different species of mammals), resemble one another and resemble man in the structure of their skeletons, in their internal organs, and in the way they feed their young. All have at least some hair on their skin. All show degrees of intelligence and are capable of being educated. For these reasons the mammals are often called the "highest" animals.

Pupil Activities

1. If possible, visit a zoo or natural history museum. Gather facts of interest about one mammal in each of the orders. Are there any mammalian orders not represented?

2. Make plaster casts of the tracks of mammals. (See Mann and Hastings, and others.) If you can get dogs, cats, rabbits, and white mice, you can take their footprints by wetting their feet with ink and leading them across sheets of wrapping paper.

3. Construct a model of a beaver dam and lodge. Study pictures. Use twigs, clay (for mud), etc.

4. Collect pictures of mammals and group them according to order. Paste them on charts or in a looseleaf notebook.

5. Prepare special reports on topics such as the following:
   (*a*) The intelligence of the great apes.
   (*b*) The mammals of a special region, such as Australia.
   (*c*) The mammals of my vicinity.
   (*d*) Man's use of mammals.

6. Since the class Mammalia is so large, you and your classmates might organize committees to make a special study of the different orders. If written reports are prepared, the class might write its own Natural History.

7. Breed white mice, guinea pigs, or rabbits, so that live mammals are available for study.

8. How does the horse walk? Observe one closely. Does it move one leg at a time? two? more? How does it maintain its balance?

9. How do dogs and cats walk? Can you prepare a series of diagrams to show the positions of their legs? Use simple lines but try to be accurate.

10. Make a comparative study of the running movements of animals.

11. Which of the common small mammals is the fastest runner? How can you check your opinion?

12. The habits of wild animals make a suitable study for the young biologist. If you can, learn something about the life of one of the following: rabbit, woodchuck, chipmunk, squirrel, prairie dog, deer. If possible, take "notes" with a camera.

13. When you have finished the chapter gather together all the important ideas you have learned about mammals under the following headings: list of the principal orders, with examples; the uses of mammals to man; the harm done to man by mammals; unusual mammals; mistaken ideas and superstitions about mammals.

Good Books to Read

Anthony, H. E., *Field Book of North American Mammals.* Putnam.
Blair, W. R., *In the Zoo.* Scribner.
Brown, C. E., *My Animal Friends.* Blue Ribbon.
Burroughs, J., *Squirrels and Other Fur Bearers.* Houghton Mifflin.
Daglish, E. F., *Life Story of Beasts.* Morrow.
Ealand, C. A., *Marvels of Animal Ingenuity.* Lippincott.
Eipper, P., *Animals Looking at You.* Viking.
Jaeger, E. C., *Denizens of the Desert.* Houghton Mifflin.
Mann, P. B. and Hastings, G. T., *Out of Doors.* Holt.
Mills, E. A., *The Grizzly.* Houghton Mifflin.
Roberts, C. D. G., *Watchers of the Trails.* Nelson.
School Nature League, *Mammals for the Nature Room.* School Nature League, New York City.
Seton, E. T., *Wild Animals at Home.* Doubleday Doran.
Warren, E. R., *The Beaver.* Williams and Wilkins.

CHAPTER III

GETTING ACQUAINTED WITH BIRDS

The characteristics of birds. (*Class Aves.*) The most striking characteristic of birds is also the most important in determining the classification: their feathers. Fortunately, there are no exceptions to the rule so that it is easy to decide whether or not an animal belongs to this class. The feathers are usually lacking on the legs, which are covered with scales. There are two other characteristics almost as striking as the first: birds have beaks or bills without teeth, and the forelimbs of birds have the structure of wings.

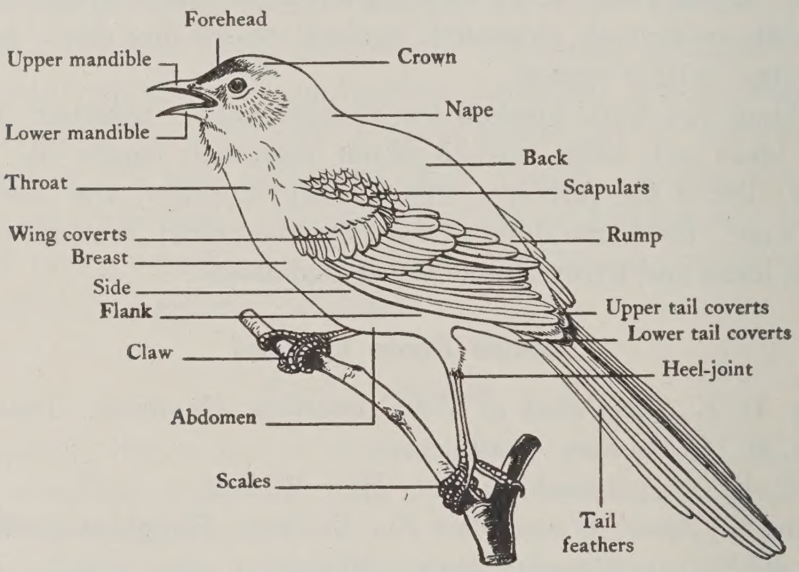
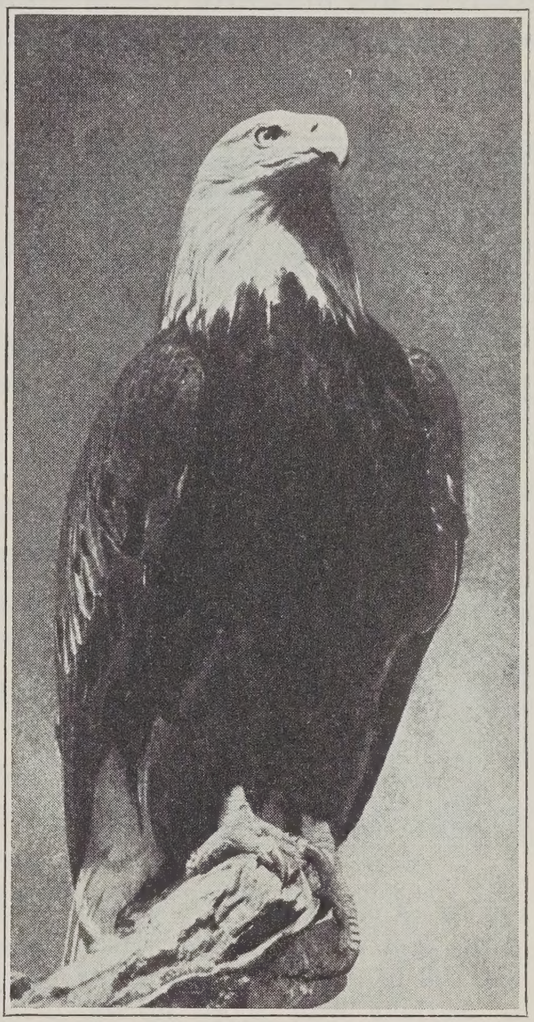

Forehead
Upper mandible
Crown
Nape
Lower mandible
Back
Throat
Scapulars
Wing coverts
Rump
Breast
Side
Flank
Upper tail coverts
Lower tail coverts
Claw
Heel-joint
Abdomen
Scales
Tail feathers

FIG. 25. It is helpful to know these names when learning to identify the common birds. Could you describe the colors of a robin or of a canary, using some of these words?

Birds, like mammals, are warm-blooded; their temperature, in general, is higher than that of mammals. Some of them, indeed, have a temperature of 112 degrees F. They have four-chambered hearts and breathe by means of lungs.

Subdivisions of the class. This class is subdivided into many different orders but the differences between the orders are so technical and so difficult to understand that it is not worth while to attempt to learn the classification unless you wish to become a true student of birds (*ornithologist*). In this chapter, therefore, birds are separated in a simple way into groups which are easy to distinguish: birds of prey, scratching birds, perching birds, birds that wade or swim, and birds which cannot fly. You will see that this grouping is largely determined by the kind of feet and bill possessed by the bird.



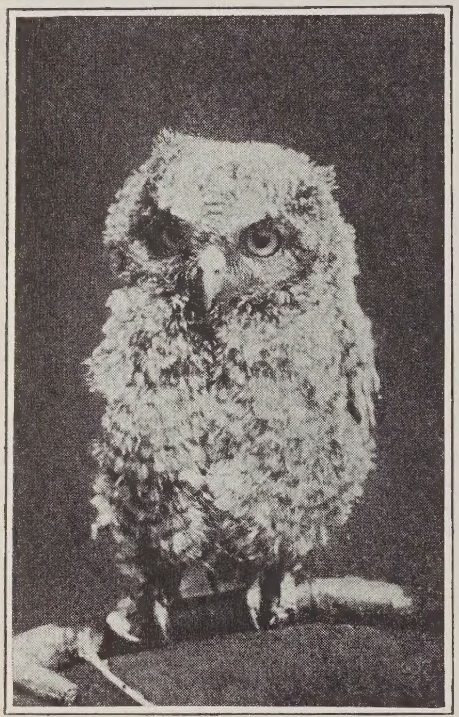
Courtesy Nature Magazine

FIG. 26. The American Eagle. How is this bird fitted for obtaining food? (*Photo by A. H. Fisher*)

Birds of prey. These are the powerful lords of the air, the eagles, hawks, vultures, and owls. Their wings spread wide and firm; their talons (claws) are cruel curved daggers which can be driven deep into a rabbit's body; their strong beaks are hooked and sharp for tearing flesh. Some hawks, eagles, and vultures are easily recognized in flight because of their remarkable ability to soar; that is, to remain aloft with almost no movement of the wings. They can do this by taking advantage of the air currents.

All birds, and the birds of prey particularly, have remarkable eyesight. Vultures, eagles, and hawks, circling high above the tree tops, sometimes a mile up in the sky, will dive straight down like a plunging airplane and pounce upon their prey. The eyes of the owl are equally keen, but only at night. In the daytime the large pupils admit so much light that the owl is dazzled. It remains well hidden in the forest or in some dark corner of a barn. At night, when the light is dim, the large pupils are an advantage to the bird; then the owl hunts for its food. And its soft, fluffy feathers enable it to swoop down noiselessly on its prey.

You may have thought of the birds of prey as your enemies; in reality, they are, with few exceptions, useful to man. Were it not for them, rabbits, field mice, and other small mammals, even certain species of insects, would increase alarmingly. There was a time when many states paid a reward for the scalp of every hawk or owl. That is past. Farmers' associations have learned that it is better to lose some song birds or an occasional chicken than to have their crops destroyed by rodents or other pests.



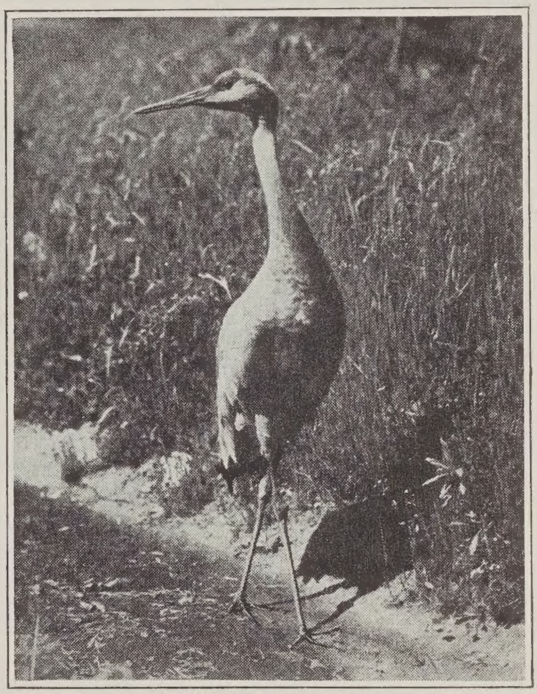
Courtesy Amer. Mus. Nat. Hist.

FIG. 27. A young owl. The pupils of the eyes are enormous. How does this help the owl? Compare its feathers with those of the eagle. (*Photo by Frank Overton*)

The vultures and some of their relatives serve man in another way. They do an excellent job as scavengers, feeding on the dead and decaying flesh of animals. African explorers say that vultures, helped by the ever-watchful hyenas and jackals, can remove every scrap of flesh from the body of an elephant, down to the skeleton, in a day.

Scratching birds. In great contrast to the birds of prey are the birds that live on the ground and scratch for seeds and small insects; such are the common fowl, the grouse or partridge, and the turkey. To be sure, some of these birds are strong and swift flyers, too, but for the most part they rely on their legs instead of their wings. Their bodies are so heavy that they beat their wings rapidly when in flight. The domestic fowl has practically lost the power of flight; by struggling hard it can reach the lower branches of a tree or flutter up to its roost in the henhouse. Such flying lacks the graceful glide of the swallow or the enduring speed of the wild duck.

Birds that wade or swim. These are, for the most part, large-sized birds that squawk and call hoarsely but never sing. They are called water birds because their food comes from the water and they spend much of their time in it or on it. The storks, the herons, the cranes, and flamingos (fla-ming′gos) wade. Their tall legs keep their bodies well out of the water and their long pointed beaks and flexible necks make it possible for them to snatch the frogs or fish that make up their diet. The widespreading toes prevent them from sinking into the sand or mud as they strut through the shallow waters. Of course, like all water birds they build nests on land, some choosing the ground, others the branches of trees, while the sociable storks select as homes the walls or roof tops of a town. You have undoubtedly seen pictures of foreign cities with the stork's nest — a large mass of coarse sticks—perched on the church steeple.



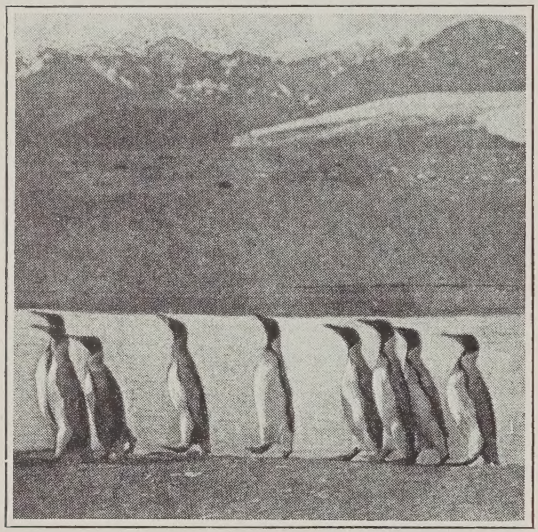
Courtesy N. Y. Zoological Society

FIG. 28. Compare the position of the eyes of this sandhill crane with the position of the owl's eyes. At whom was the bird looking?

Among the swimming birds are the ducks, geese, and swans. They, too, may wade along the shore but for the most part they swim on or under the water. Some, several species of ducks and the laughing loon, are excellent divers, able to swim under water for long distances. Their legs are strong and attached far back so that they can exert a powerful push against the water. The position of the legs makes it easy for them to tip their heads down for a dive. Their feet are large and webbed. Water birds are all provided with oil glands which protect them from a wetting. The common expression, "as water rolls off a duck's back" shows how useful is this device of water birds.

Some swimming birds, like the gulls, spend as much time on the wing as in the water. You may have seen them now and then bobbing on the waves in harbors or rivers but more often circling low behind some vessel, diving for stray bits of garbage or for fish. They will follow a ship far out into the ocean, as effective scavengers on the sea as are the vultures and buzzards on land.

The petrels, relatives of the gulls, are frail little birds, smaller than the robin. They remain away from land for days at a time, flying in the trough of a wave or resting on its crest. In mid-Atlantic the stormy petrel may be seen, a tiny speck skimming over the tops of the breaking waves. Living and feeding on the ocean, they occasionally perch for a brief moment on a passing vessel. Sailors call them Mother Carey's chickens.



Courtesy Amer. Mus. Nat. Hist.

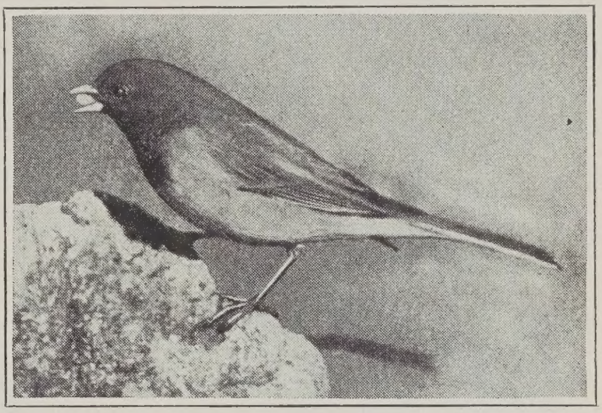
FIG. 29. The penguin is an amusing bird. How is it adapted for life in a cold land where few plants grow?

The most interesting of all the water birds is the penguin, which lives in the icy wastes of the Antarctic. Its wings are shaped like flippers and covered with short feathers almost like scales. Under water it is swift and sure. It can dive off an ice floe and catch fish as easily and as gracefully as a seal. But on land it waddles about as if its legs had no joints. Its wings, which are never used for flight, are kept pressed closely against its sides. Antarctic explorers relate that penguins are totally unafraid of man. Overwhelmed with curiosity, as are so many animals, they lose no time in becoming acquainted with those who land on the rocky ice shores where the penguins nest.

Birds which cannot fly. There are a few species, living wholly on land, which never fly. The ostrich, the largest living bird, and its less familiar relatives, have wings which are too small to be of use. But all these birds are good runners. Men in automobiles have timed them at sixty miles an hour, and they can keep up a fast trot for long periods of time. When attacked and cornered the ostrich defends itself by means of a kick which is dangerous to a grown man.

Perching birds — the birds that sing. This group of birds includes those with which you are probably most familiar. You may know best the house (English) sparrow and the starling of our crowded cities; the robin and the bluebird of our suburbs; or the swallow and the crow of the countryside. These, and about four hundred fifty other species, are perching birds. They are the birds to which man owes thanks for keeping down insect pests and for eating seeds of weeds that would spoil crops and gardens. Of course, when grapes and cherries begin to ripen the song birds often steal them from the farmer. For this reason robins are considered unwelcome visitors in the grape belt of New York state. But, in general, birds eat fruits only as "dessert." The rest of their bill of fare consists largely of harmful insects.

One close look at the bill will often tell you what is the general character of a bird's food. But closer study is necessary to discover exactly what it eats. The careless, dashing kingbird captures insects on the wing; the painstaking, methodical nuthatch goes over the bark of a tree as if with a magnifying glass, discovering the unsuspecting insect borers hidden deep in the wood; the bustling warblers flit and hop lightly among the outermost twigs of a tree searching for insects among the leaves. The life of an insect is insecure; there is usually some kind of bird with bill and feet especially fitted for its capture.



Courtesy Nature Magazine

FIG. 30. The Sierra Junco. With three toes in front and one behind, it is well fitted for grasping the perch.

Among seed eaters, too, there are variations in the bill, most curious of which, perhaps, is that of the bird known as the crossbill which feeds on seeds of pines. Its bill, seemingly as useless as a pair of scissors whose points do not meet, is just the right thing for stripping the cones of their seeds.

Birds that fool man with their plumage. Some birds are so strikingly colored that it would seem to be easy to recognize them. Such are the scarlet tanager, the Baltimore oriole with its black and orange plumage, and the red-winged blackbird. But these birds are not in all cases as easy to recognize as you might suppose. It is only the male that flaunts this plumage. The female is quietly dressed in brown and greenish shades which blend with the foliage (leaves) when she sits on her nest. Knowing the male by sight is only half the story. To make it more difficult, in some cases, not only does the male differ from the female, but both may be different from the young. In the case of some of our common birds, the bobolink and others, there is another complication, the male himself has two suits of clothes. He changes after the breeding season.

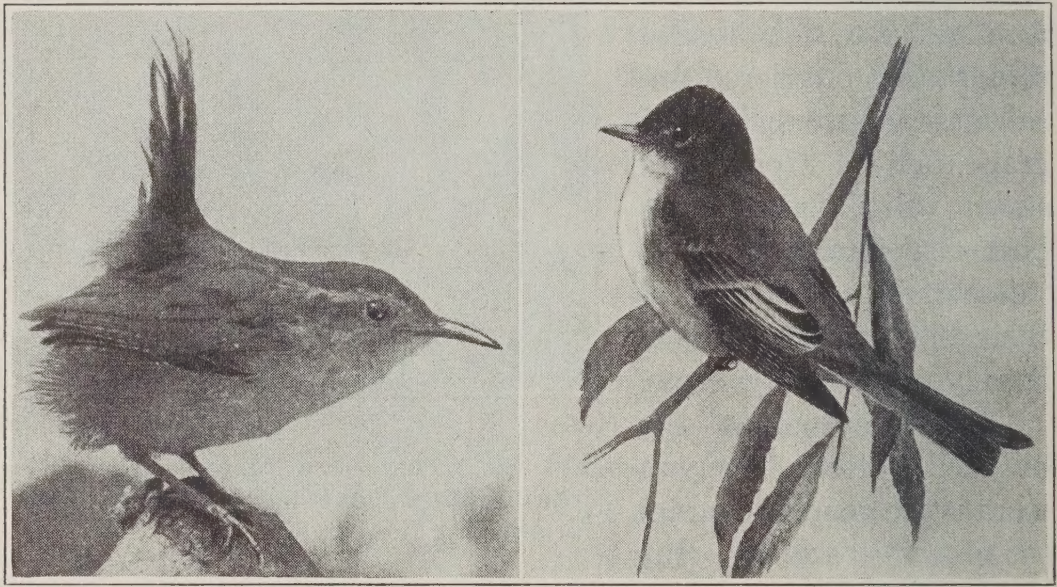


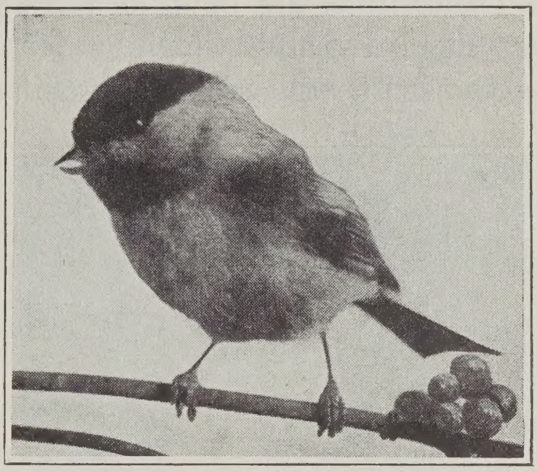
Photo by Hugh Davis *Courtesy U. S. Bur. Biological Survey*

The Carolina Wren The Phoebe

Fig. 31. What striking features other than markings would enable you to recognize these birds?

Learning the names of birds. Once you have made a beginning and learned the names of a few birds this becomes a fascinating game, and far more fun than you might suppose. Evidently, you cannot depend on recognizing them by their brilliant color or conspicuous markings alone. With experience, you learn to look for a combination of characteristics: their size, length of tail, crest on the head, markings on the wings, method of flight, and behavior or habits.

Bird lovers learn to recognize the many kinds of perching birds in other ways, often by their calls and songs. When you see a flock of little black-capped birds alight on the tree beside you they introduce themselves by their unmistakable "chick-a-dee-dee-dee." The shrill "teacher, teacher, teacher" heard in the woods helps you to identify the dull-colored ovenbird or teacher bird. The plaintive high-pitched "pe-ah-whee," "pee-wee" announces the presence of the little wood pewee high up in some distant tree. There are many birds whose calls or songs are easily recognized.



Courtesy Amer. Mus. Nat. Hist.

FIG. 32. By what marking can you recognize the chickadee?

Birds' nests. It is helpful in learning to identify birds to study their nests and eggs. When you discover a baglike nest suspended from the outermost branches of some tall elm you need not wait to see the occupants. That is the home of the Baltimore oriole. Each species of bird prefers a particular kind of location and special materials with which to build its nest. The chipping sparrow uses horsehair as lining, the hummingbird seeks plant fibers, lichens, and cobwebs. If the desired materials are lacking birds will often use anything that can be woven with bills and feet: wool, feathers, moss, paper, even pieces of wire or hairpins! Some birds of course do not weave, but plaster. If under the eaves of your barn you see a cup-shaped nest of mud, it is a cliff swallow that has come to live with you. In fact, you are likely

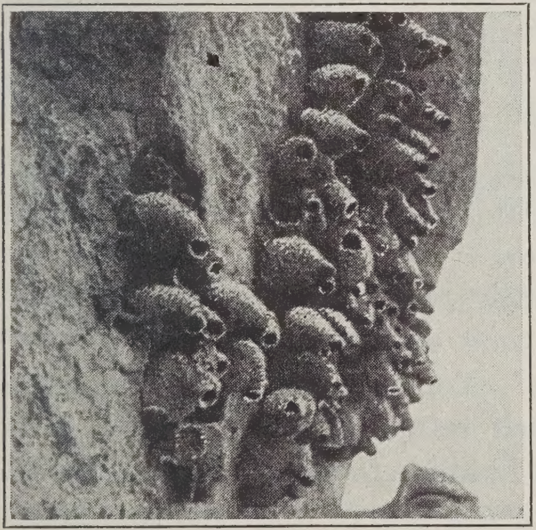
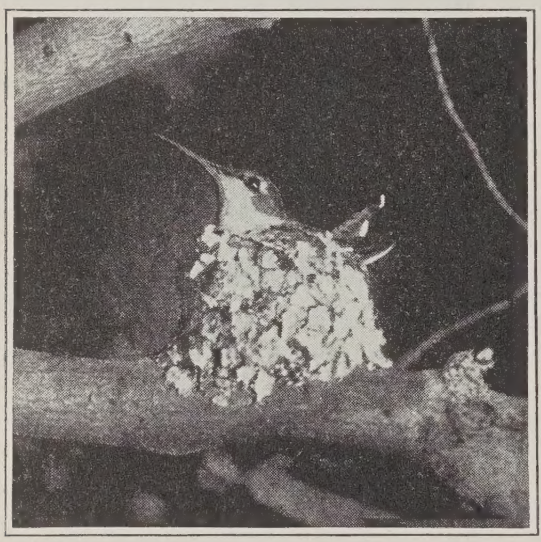


Photo by H. H. Johnson

FIG. 33. The nests of the cliff swallow. How do these nests differ from the nest of the hummingbird?

to see a whole row of such nests, for swallows usually live in colonies.

Other nests are made of sticks, not woven but glued together by the bird's saliva which hardens like mortar. Such are the nests of the swift, which builds in chimneys. Small fires on the hearth help to harden the "mortar" and give a pleasant warmth to the fledglings (young birds) in the nest. But a good blaze and rising sparks may prove disastrous to the birds.

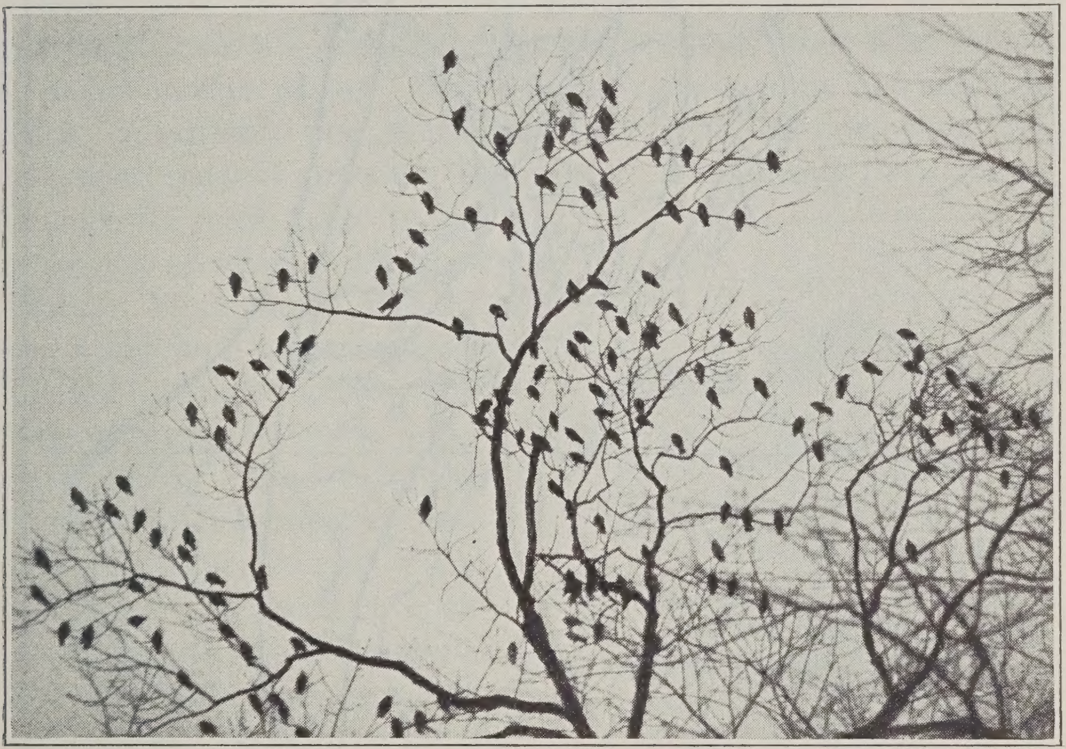


Courtesy Amer. Mus. Nat. Hist.

FIG. 34. The tiny hummingbird sitting on her nest. How does the nest help the bird to raise a family? (*Photo by Frank Overton*)

Migration of birds. To see the ostrich and the penguin in their natural homes you have to travel far. It is only the explorer who has this good fortune. But even if you stay right at home you may become acquainted with many different birds. In the latitude of New York, you are likely to see a large variety of birds throughout the four seasons, for birds are themselves explorers and travel far. The busiest traveling season is the spring. It is then that vast numbers of birds come back from the south. Some stay in this country throughout the summer to rear their young; they are the summer residents. Some stay a short time only and fly beyond your home to more northerly regions. You can look for these birds again in the late summer on their return trip southward; they are the transients, probably less familiar to you. There are still others, such as sea gulls, which come to live with you in winter. These "winter residents" come from the north in search of warmer climates. This habit of flying from one home to another and back again each year is called *migration.*

The mysteries of migration. Some birds travel enormous distances when migrating. The arctic tern, a water bird, builds its nest in the far north. Several months later, when its young are old enough, it flies to the Antarctic. Although its route has not yet been completely traced, it is known that it flies 11,000 miles each way. The birds live in the north when it is summer there and in the south when that hemisphere is warm. A few months are spent in each home; the rest of the year is spent on the wing. The golden plover is another bird that goes from the far north to the far south, from Canada to South America, flying about 2000 miles or more over the ocean in one stretch. In the space of two days and two nights it completes its sea journey without stopping to rest and feed.



Courtesy New York Zoological Society

Fig. 35. Starlings resting during migration. Of what advantage is migration to the bird?

Some birds, especially those that catch insects while on the wing, migrate by day; some, like the sparrows and warblers, feed on land by day and fly by night. Some travel singly, some in flocks. Most birds follow definite routes in migration. By collecting reports from many students of birds, it has been possible to map some of these routes.

There are many interesting questions connected with migration still unsolved by the biologist. "How can birds travel so far without food or rest?" "How can they find their way?" "How can

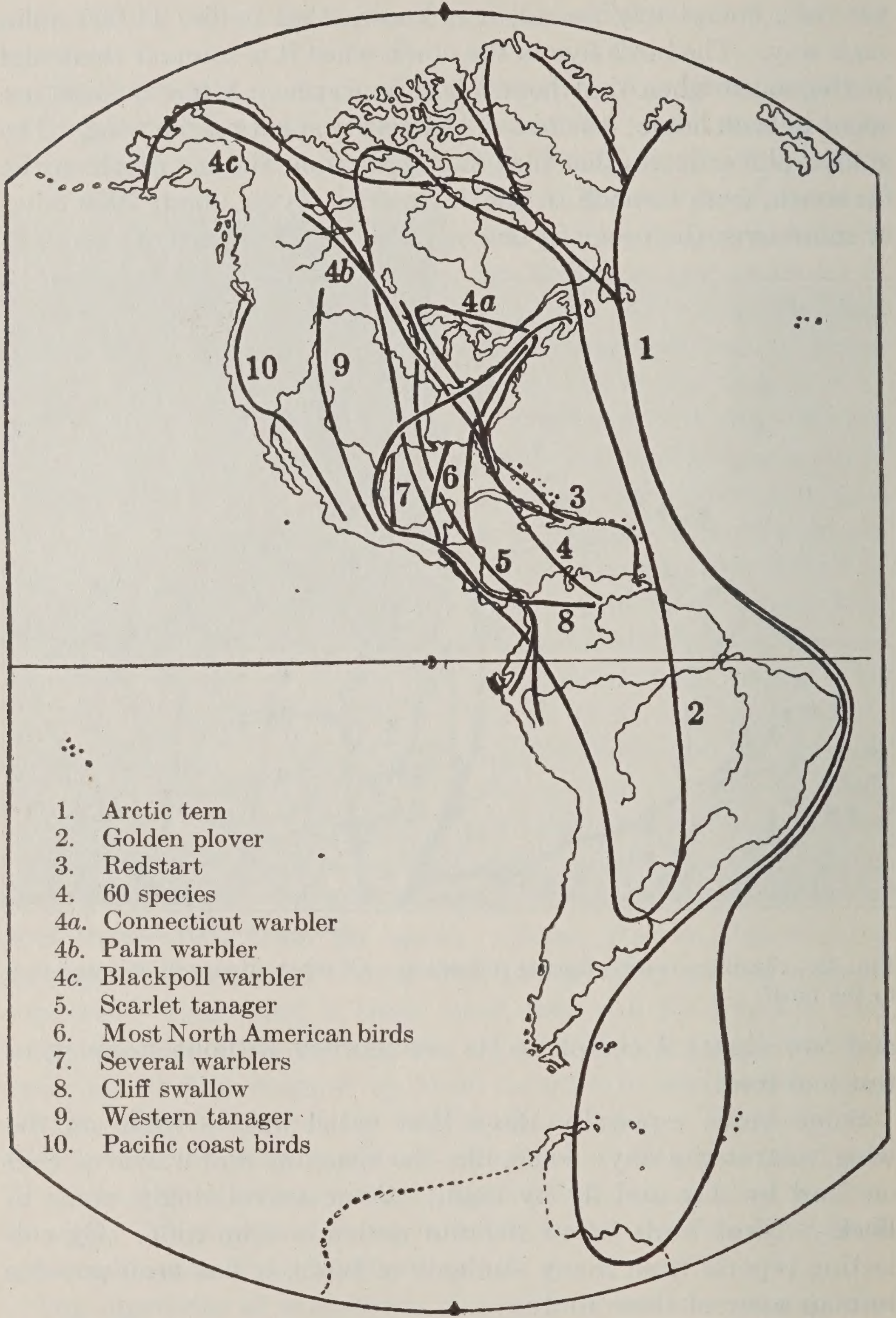
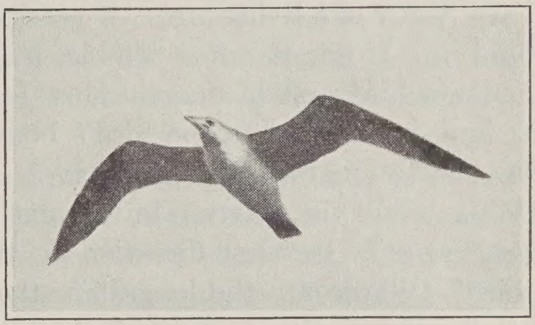

4c
4b
4a
1
10
9
3
7
6
4
5
8
2
1. Arctic tern
2. Golden plover
3. Redstart
4. 60 species
4a. Connecticut warbler
4b. Palm warbler
4c. Blackpoll warbler
5. Scarlet tanager
6. Most North American birds
7. Several warblers
8. Cliff swallow
9. Western tanager
10. Pacific coast birds

Fig. 36. Map Showing Migration Routes

some return not only to the same state and town but to the very same nest in which they were reared?" And difficult as any: "What makes birds migrate, anyway?" Certainly it is an advantage to them to go off to warmer climates where insects thrive and seeds are not covered by snow. But how does the bird know this? And even if the bird did know, why does it not stay in the south in summer, too?

Bird flight. Have you ever watched a goldfinch fly? Here you can see the various steps in the process as though they were shown in a slow motion picture. The goldfinch seems to fly in a series of leaps. A powerful beat of its wings against the air downward and backward sends it upward and forward. Then during the moment it holds its wings close to its body it descends a little in a swoop. Its flight is slightly like a ride on a roller coaster. Those birds that have a more steady flight do not bring their wings close to their bodies, but flap them up and down. Their large wing feathers are fastened in such a way that they overlap while the wing beats backward, but separate as the wing comes forward and up. At this time little resistance is offered to the air and not much momentum is lost. When birds soar, they move their wings very little; instead, they depend on air currents, just as a glider does.



Courtesy Amer. Mus. Nat. Hist.

Fig. 37. Sea gull flying. What does the bird do with its legs when flying? What use does it make of its tail?

The remarkable thing about the flight of birds is the speed with which they fly and the endurance they sometimes show. Some birds are said to fly as much as 200 miles an hour. What enables a bird to accomplish this remarkable feat? Its wings are enormously long as compared to the size of its body. And to move these wings it has very powerful breast muscles. All birds have these. Even the chicken which does not use its wings much, has fairly large breast muscles (white meat of the body). When next you see a chicken carved, compare these muscles with the muscles along its back (brown meat of the body). Notice, too, the extraordinary breast bone to which the muscles are attached; it is large and curved and shaped like the keel of a ship.

A bird is fitted for flight in many other ways. Most of its tiny body cavity is taken up with huge lungs so that enough air can be taken in during the severe exercise of flying. The bones are hollow, making the body exceptionally light in weight. Man makes use of the same device. When building bicycles and other machines he gets sufficient strength and reduces weight by using hollow tubes instead of solid bars. This is not the only case in which man has learned lessons from nature.

Pupil Activities

1. Study of a living bird. If possible, observe a canary or a pigeon or a chicken. If one is not available, study a house sparrow or some other common bird, out of doors. How long is the bird? If you can handle it, find out how large the bird's body is and how wide a wingspread it has. What markings does it have? Describe their location accurately. (Make use of the diagram in the text.) How far down on the legs do the feathers go? In what direction do the feathers on the wings and body point? Where are the longest feathers? the shortest? How many toes has the bird? When it stands, how are the toes placed? Where are the eyes? What color are they? Does the bird blink? If so, what covers the eye? How far around can the bird turn its head? How long is the beak? What color is it? What is its shape? How does the bird use its neck, head, and beak to get food? Does it use its toes? How?

2. Have you ever looked closely at a feather? Cut the quill crosswise to find out why it is so light. Use a hand lens for the study of the other parts. Cut a point on the end of a large quill and use it as a pen.

3. In what ways is a bird well fitted for flying? Compare your list with others prepared by your classmates. (*Hint.* Do not forget to add what you have noticed about chicken bones as compared with lamb bones.)

4. If there is no Junior Audubon Society in your school, ask the class secretary to write to the National Association of Audubon Societies, 1775 Broadway, New York City, for further information.

5. Are you a Scout? Have you earned the Bird Study Merit Badge?

6. Even if you live in a city it will be easy for you to raise pigeons on the roof. You will find these birds interesting to watch and breed.

7. Write to the Geological Survey, Washington, D. C., about bird-banding. Read the *National Geographic Magazine*, January, 1928. Report to the class on the subject.

8. Can you get birds to stay in your neighborhood? Establish winter feeding stations. See National Association Audubon Societies leaflets; or Allen, *Book of Bird Life.*

9. If you are good at making things with your hands, build bird houses and bird baths. You will enjoy watching the birds. See L. H. Baxter, *Boy Bird-House Architecture.*

10. Learn to recognize twenty common birds. Send for free pictures of birds to the Singer Sewing Machine Co., New York City, and the manufacturers of Coca-Cola. These will help you.

11. Collect pictures of birds and group them correctly in a scrapbook. Use the simple classification given in the text, or better still, consult a book like Chapman's and classify them scientifically.

12. Do you know any birds by their calls or songs? Some of them are very easy to recognize. See A. R. Brand, *Songs of Wild Birds.* Get phonograph records.

13. Make a collection of deserted nests and demonstrate to the class. How many different kinds of materials go into the making of these nests? (Do not collect nests still in use.)

14. When you have learned to recognize many kinds of birds you would enjoy making a "bird census." List all the birds found in your locality.

15. Make a large chart to illustrate some bird migration routes. Send for Bulletin No. 185, U. S. Department of Agriculture, or read A. Wetmore, *The Migrations of Birds*, and other bird books.

16. Make a bird calendar, monthly or weekly, to show which birds are in your neighborhood at each time. Diagrams of the birds may be traced and colored.

17. In the fall of the year when birds are migrating in large numbers you may find dead birds. Prepare bird skins and bird skeleton. See Turtox leaflets No. 41 and No. 9. Write to the General Biological Supply Company, Chicago, Illinois, for these.

18. Bird photography is a fascinating hobby. Much information can be obtained from the Camera departments of *Nature Magazine* and magazines on camping, hunting, and fishing. The finest achievement is a series of pictures showing the life of the bird from egg to adult.

19. *Summary.* Do you know the characteristics of birds, a simple classification, the names of birds in each group, and some interesting habits of birds? If so, you have increased your list of friends.

Good Books to Read

Allen, A. A., *American Bird Biographies.* Comstock. *Book of Bird Life.* Van Nostrand.
Bailey, F. M., *Handbook of Birds of Western North America.* Houghton Mifflin.
Chapman, F. M., *What Bird Is That?* Appleton-Century.
Daglish, E. F., *Life Story of Birds.* Morrow.
Dugmore, A. R., *Bird Homes.* Doubleday.
Huxley, J., *Bird-Watching and Bird-Behaviour.* Chatto and Windus. (England).
Job, H. K., *How to Study Birds.* Outing Publishing Co.
Patteson, S. L., *How to Have Bird Neighbors.* Heath.
Peterson, R. T., *Field Guide to the Birds.* Houghton Mifflin.
School Nature League, *Bird Migration.* School Nature League, N. Y. C.
Walter, H. E. and Walter, A. H., *Wild Birds in City Parks.* Macmillan.

CHAPTER IV

GETTING ACQUAINTED WITH REPTILES AND AMPHIBIA

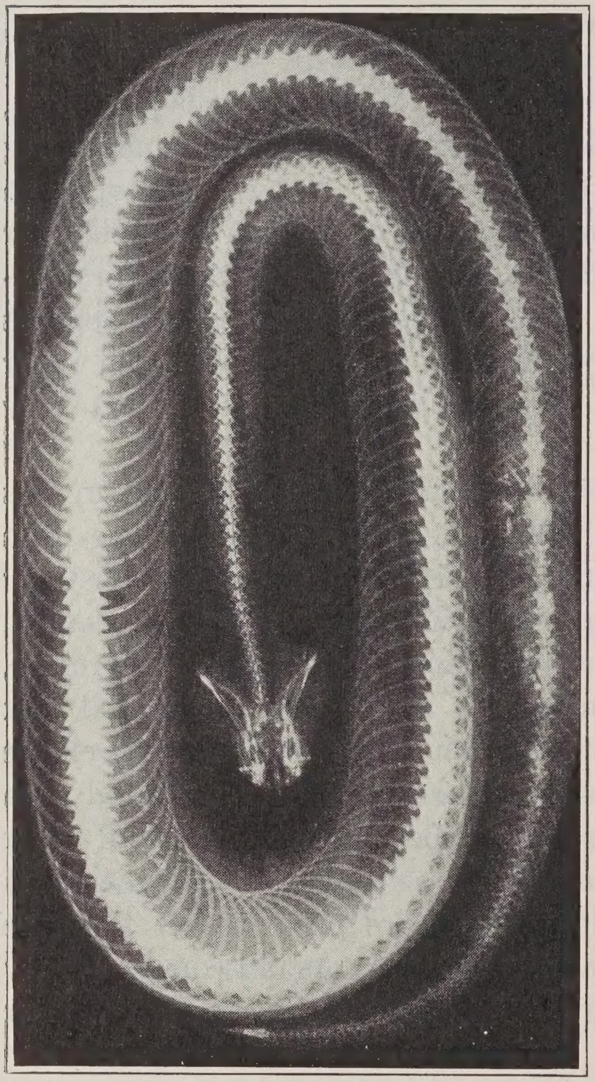
What is a reptile? (*Class Reptilia.*) Like mammals and birds, reptiles have lungs. Some lay eggs as do the birds; some bring forth the young alive as do the mammals. Yet not one of them has mammary glands. Besides, instead of a covering of hair or feathers they have scales. Scales, you remember, are characteristic of fish also. How, then, can one distinguish between reptiles and fish? This is easy, for fish, as you know, breathe in the water and do not have true lungs. Reptiles are the animals with scaly skins and lungs.

Reptiles are the first vertebrate animals you have met in this book that are cold-blooded. What is really meant by the term "cold-blooded" is that the animal's temperature is not constant; it is determined by that of the surroundings, whether air, earth, or water. The body of the cold-blooded animal is, therefore, sometimes warm and sometimes cold. Naturally, the animal that takes on the temperature of its surroundings is limited in its choice of a home. In the tropics you may become best acquainted with reptiles and as you travel northward you may expect to find fewer and fewer reptiles. In a climate such as that of the northeastern states where winters are cold, reptiles are present, but they are active or visible during only a short season. As fall comes on they become sluggish and soon go into a state of *hibernation* (winter sleep) underground.

Reptiles are varied in their form and in their habits. Some can swim, others climb trees or glide through the air. Some run on four legs, some on two. Some wriggle with amazing agility without any legs at all. Some move with great speed, others lumber along awkwardly with their houses on their backs. Many live on land; others dwell in fresh water or in the salty oceans. *Zoologists* (zoh-ol′o-gists — biologists who study animals) divide them into three main orders which you easily recognize: the snakes and lizards, the alligators and crocodiles, and the turtles.

Some mistaken notions about snakes. Snakes are difficult to catch and difficult to keep; until recently, they were little studied. Because of ignorance many superstitions arose. As a result there is much that many of you have to unlearn about reptiles in general, but particularly about snakes. In the first place most snakes are harmless. In our country there are only four kinds of poisonous snakes: the rattlesnake, the copperhead, the moccasin, and the coral snake.

Rattlers are widely scattered over the United States; the copperhead is found in various regions in the northern half of the country; the water moccasin and coral snake are not uncommon in the south; but, in general, poisonous snakes are the exception, not the rule. Furthermore, snakes are timid and want to be let alone. Aside from the water moccasins, they do not attack unless disturbed. Man is rarely bitten, even where poisonous snakes are numerous. Still more rarely does he die of the bite. An understanding of the methods of treating a bite and the courage to remain calm almost always prevent serious results from the poison. But carelessness may result in disaster.



Courtesy General Electric X-ray Corp.

FIG. 38. This X-ray photograph of a snake shows its long backbone and many ribs.

No snake that lives in this part of the world blows poison from its mouth! The swiftly-moving, dangerous-looking little tongue contains no poison, either. It is utterly harmless; the snake uses it to learn of its surroundings as the grasshopper uses its feelers. The poison, when it is present, comes through a pair of large, hollow, very sharp fangs. The fangs are in the upper jaw, folded back out of the way until the snake strikes.

Snakes take their place in the world just as do other living things. They serve as food for other animals; they themselves eat smaller snakes, birds, and rodents. When these rodents are those that damage crops, snakes are useful to man. In wheat-growing regions the bull snake is the farmer's best friend, for it crushes to death and eats large numbers of field mice and other rodents which destroy wheat plants. The feeling of horror that snakes arouse in some people is unreasonable. You may shrink when you see a snake; as a child you learned to imitate your elders. Children left to themselves have no more fear of snakes than of any other animal. Of course, any creature that moves quickly startles you. The partridge that whirrs up from the dead leaves close to your feet makes you start, but does not inspire fear or horror. Neither need the sudden movements of a snake. Both animals are merely trying to escape you.

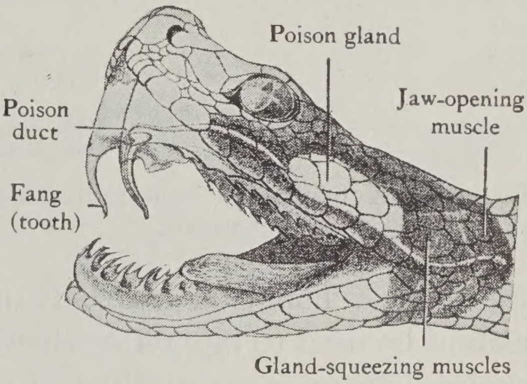
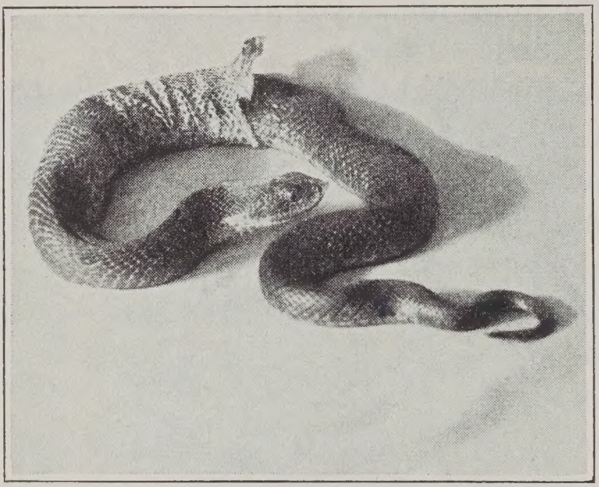


FIG. 39. The head of a rattlesnake ready to strike.

Have you heard about the snake that swallows the end of its tail and rolls like a hoop? There is no such snake. Have you read of the "milk snake" that steals milk from the cows in the barnyard? No farmer has ever seen a snake milking a cow, in spite of all the tales he may tell. These are superstitions. And so, of course, is the belief that horsehairs left in water will turn into snakes!

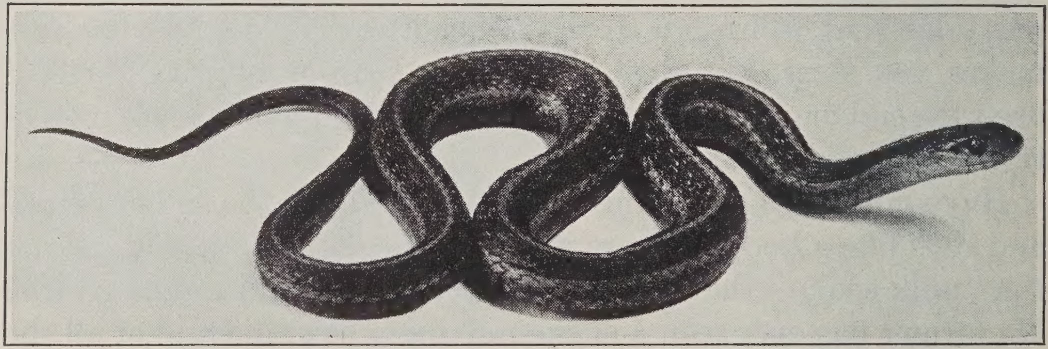
Peculiarities of snakes. Snakes have an enormously lengthened backbone, consisting of a far larger number of separate little bones (vertebrae— ver′te-bree) than is found in the backbones of mammals or birds. They also have ribs extending the whole length of the body. Muscles connect the ribs with the scales on the lower part of the snake. By moving the ribs, the scales are hooked on to the uneven surface of the ground, one after the other. Thus the snake really wriggles on its scales, but this happens so fast and evenly that it looks like a smooth gliding motion. No snakes have legs to help them in locomotion, although the pythons of Asia have tiny stumps of hind legs which are not used.



Courtesy Amer. Mus. Nat. Hist.

FIG. 40. A hog-nosed snake shedding its skin which it has outgrown.

Snakes have their jaws hinged to their skulls in an unusual way, and the lower jaw is made of several pieces which are separately movable. Because of this the mouth can be opened so wide that it will admit an animal broader than the head of the snake. This is of great advantage to the snake since its teeth cannot be used to bite off or chew its food. After a big meal, the snake shows a large swelling in the region of its stomach; as the food is digested, this swelling grows smaller.

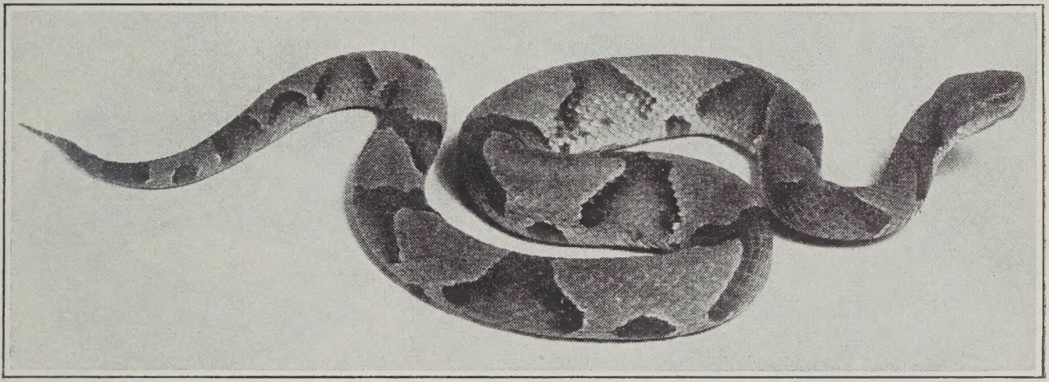


Courtesy U. S. Bureau of Biological Survey

FIG. 41. The garter snake bears its young alive.

Snakes you may meet out of doors. In this country, water snakes are common in only a few places, and not many snakes climb trees; most live on the ground. Among the commonest snakes are the various kinds of garter snakes, beautifully marked and altogether harmless. They have teeth and when cornered they do bite, but, of course, the bite is no worse than any break in the skin. The bright green grass snake is also met frequently, as is the slender, long-tailed, black snake or "blue racer." You may have seen the latter stealing birds' eggs and young. Its name comes from the fact that it is one of the swiftest of our snakes, but at that its speed is no more than three miles an hour, which is about as fast as you walk.

In many parts of the country are found the hog-nosed snakes which rear, puff up their necks, hiss, and appear altogether terrifying, but if you call their bluff they quickly collapse and roll over as if dead. They are good actors, too, and might easily fool you. Only they overact their part, for if you turn them right side up they "die" a second time and turn on their backs again! The king snakes are common in the southern states. They have the courage to attack other snakes larger than themselves, including the poisonous rattler, which they can squeeze to death.



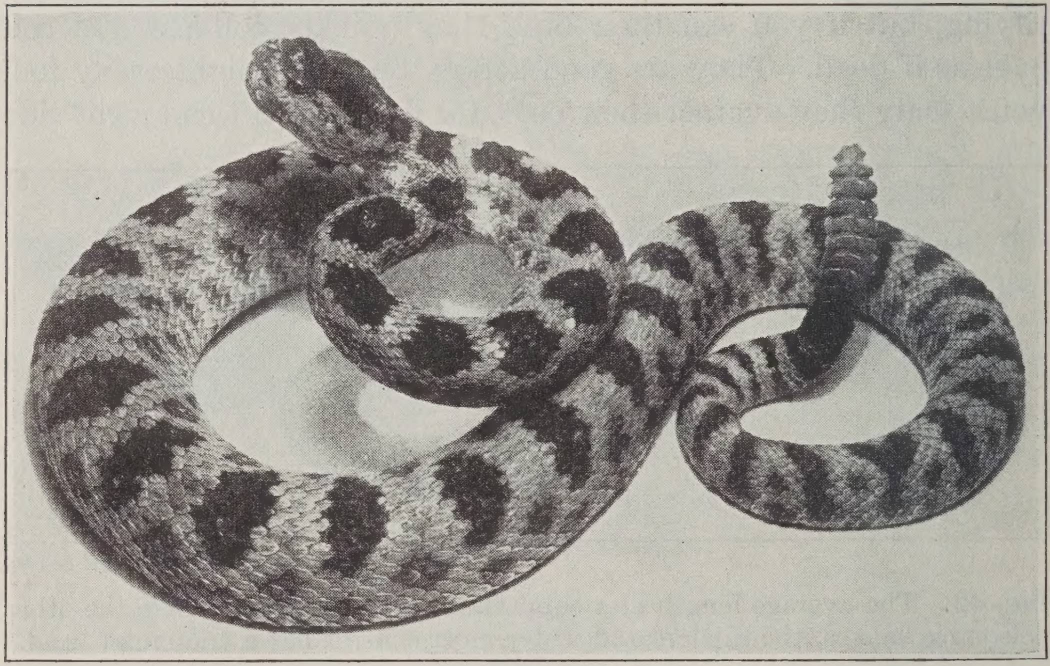
Courtesy U. S. Bureau of Biological Survey

FIG. 42. The average length of a copperhead is 2 to 2½ feet. Like the other poisonous snakes, the rattlers and water moccasins, it has a triangular head.

Rattlesnakes are fairly common in many parts of the United States. When disturbed they sound their rattles, which are located at the tip of the tail, so that it is easy to avoid them. If you approach a rattler quickly, however, it will not have time to warn you. When the snake strikes, the amount of poison injected depends on the size of the snake. Large rattlers are therefore more dangerous than small ones.

The water moccasin lives in the swamps of the southern states. It is called "cottonmouth" because the inside of its mouth is white.

Snakes one reads about. While snakes in our country are not a real danger, in India, Central America, and other tropical regions snakes are a serious menace to man. It is estimated that in India they kill about 20,000 people every year. One of the most deadly snakes is the cobra. It is vicious, and injects a particularly strong venom (poison). In these regions, too, live the huge boa (boh′a) constrictors, anacondas (ann-a-con′das), and pythons (py′thons) which coil themselves around their victims and crush them to death. Pythons are the giants of this order. Many reptiles, unlike other animals, can keep on growing throughout their lives, so that if they live long enough, as do the pythons, they may grow to an enormous size.

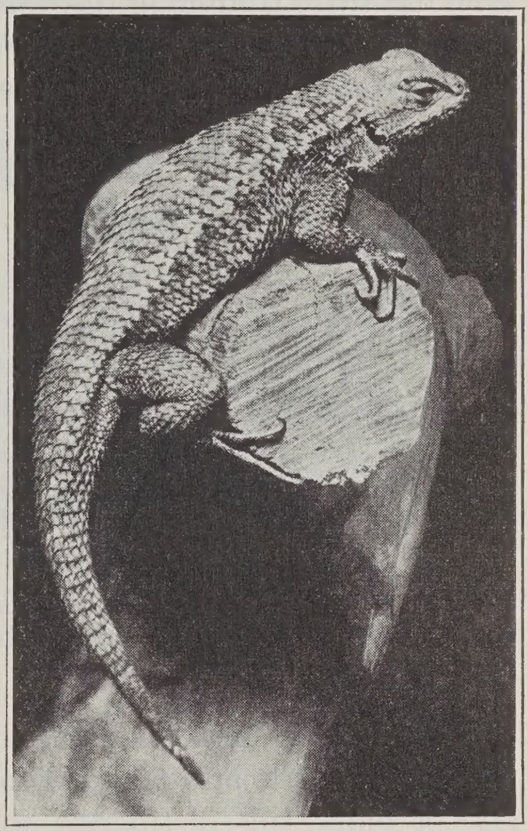


Courtesy U. S. Bureau of Biological Survey

FIG. 43. How many rattles has this rattlesnake? It is not true that one can tell a rattlesnake's age by the number of rattles.

Lizards — the closest relatives of snakes. Unless you live in a warm climate your acquaintance with lizards is probably limited to those you see in captivity. People often call the little four-legged, soft-bodied salamander, so common in the woods, a lizard; but since it lacks a scaly covering you know it cannot be a reptile, and must not be called a lizard. Lizards have, as a rule, slender bodies with long tails and four rather short legs which can move with great speed. Many lizards, like the chameleon (ka-mee′-lee-on) which is sometimes kept as a pet, are small. Chameleons are interesting to watch because they change color from time to time.

Lizards of the United States are, with one exception, harmless, but some of them have strange habits which give them a bad reputation. The innocent chameleon rolls its two eyes about independently of each other and looks quite ferocious. The timid but fierce-looking horned toad (which is not a toad at all) can wag its tail like an angry cat when it is annoyed. Thus it may terrify its enemy but it is harmless both to man and to other animals. The one lizard which bites and which has poison fangs is the red and black striped Gila monster (hee′la). It feeds on small animals and will strike at man, though its bite rarely proves fatal to him. It is larger than most of our lizards, measuring as much as twenty-four inches in length. It lives, together with many harmless species of reptiles, in the deserts of Arizona and New Mexico.

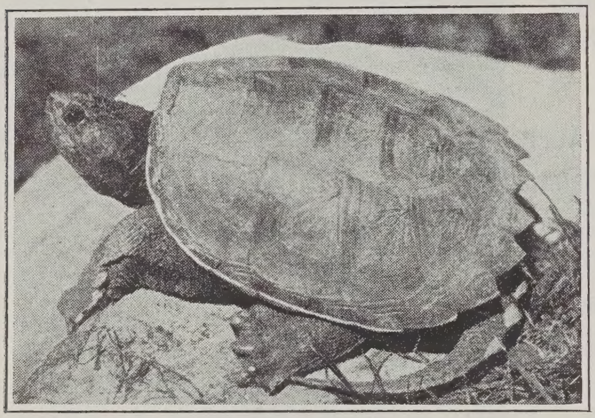


Courtesy Amer. Mus. Nat. Hist.

FIG. 44. This swift is a typical lizard. Notice the claws on its toes. What characteristics of a lizard does it show?

Alligators and crocodiles. Alligators and crocodiles are much alike. The differences between them are small and of importance to the trained biologist only. Like the lizards, they inhabit only the warmer portions of the globe. Even there they are sluggish, resting motionless in shallow streams with their eyes and nostrils above the surface of the water. However, the sight of some unwary animal along the banks will quickly rouse them to activity. With lightning rapidity the alligator snaps up its prey with its widespreading jaws. These are edged with regular, sharp teeth which make escape impossible for the victim. Sometimes the alligator uses its tail to hurl its prey into the water. When it has been held down long enough to be drowned, it may be swallowed at once or it may be stored in some recess of the banks until it is partially decayed. None of the alligators or crocodiles of our country attacks human beings but the much larger species of the Nile has little trouble in disposing of a man.

Turtles. Turtles, being vertebrates, are provided with a complete backbone, ribs, and all the other bones you should expect a "backboned" animal to have. The "shell" develops from the skin of the upper and lower surfaces. Head and legs are, of course, covered with the ordinary scales characteristic of reptiles. In a few species, the shells remain soft. In one species, the hawksbill of southern waters, the shell changes into the highly prized substance known as tortoise (tor′tus) shell.



Courtesy Amer. Mus. Nat. Hist.

Fig. 45. The snapping turtle has a dull colored shell. You can recognize it by the deep notches in the shell in back.

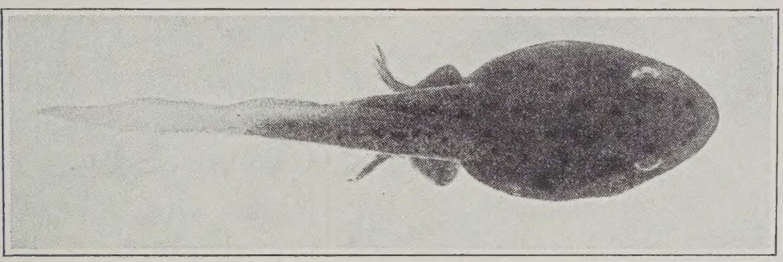
Some people speak of the land turtles as "tortoises," reserving the names turtle and terrapin for the water-living forms. Others do not make this distinction so that there is some confusion in common names. The turtles that inhabit fresh water lakes, like the painted turtle, are usually similar to the land-living species. Those that live in the ocean have feet distinctly fitted for swimming.

Sea turtles sometimes grow to a huge size. The green turtle, sold as food along the coast, may measure four feet in length and weigh as much as three good-sized men. The land tortoises of the Galápagos Islands, because of their great age, are equally large.

Turtles may eat plant food, or insects, frogs, fish, or any small animals. Their horny jaws are sharp and strong so that teeth are not needed for biting or tearing. Most turtles, fortunately, do not use these jaws except for getting food. The snapping turtle is the one exception, for it is vicious and will attack man. It can catch you off guard with its swift motions and is best left alone. You may find it floating in rivers or ponds or buried in the mud.

Most turtles can get head and legs well under cover. The box turtle can do even better. Its large lower plate is hinged so that it can be folded up against the roof, after the legs have been safely pulled in.

How amphibia differ from reptiles. (*Class Amphibia.*) Both amphibia and reptiles are cold-blooded vertebrates living in the woods, the open country, or the water, avoiding man for the most part and therefore not very familiar to you. Some people confuse reptiles and amphibia; but after one good look it is easy to distinguish them. While the reptiles are covered with dry scales, the amphibia have naked skins, which in almost all species are soft and moist. The name "amphibia" was given to them because of another characteristic shown by most of them: throughout part of their life they live in the water and breathe under water; during the other part they live on land. You all know how the frog starts life as a swimming *tadpole* or pollywog which gradually grows four little legs. When it has become a frog it is able to live on the land; many species spend much of the time in the water. Almost all return to the water to mate. There are only a few species among amphibia which never get beyond the aquatic (water-living) stage. These forms, even when full grown, resemble the legged tadpole. In the adult (full-grown) stage, most amphibia have two pairs of legs, some have only a single pair while a very few have none at all.

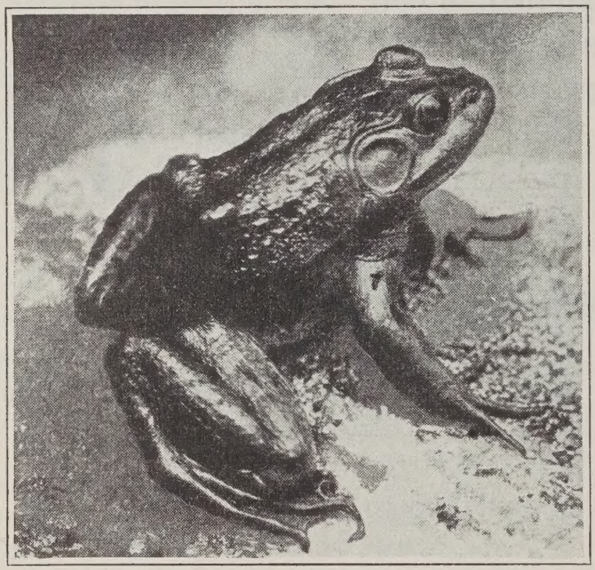


Courtesy American Museum of Natural History

FIG. 46. This tadpole is far on its way to becoming a frog. How do you know?

Amphibia with tails. The biologist divides the class Amphibia into two orders, those with tails and those without. It is the tailed forms, the salamanders and newts, which may be mistaken for lizards until they are looked at closely. They are all timid, harmless creatures; their feet have no claws and their jaws are weak, unfitted for biting. They catch insects with the tongue. There is a giant salamander, found in China and Japan, that grows to be almost as large as a man, but the large species of our country, the hellbender and the mud puppy, reach a length of only one and a half to two feet.

Some of the tailed amphibia are brightly colored; others, like the hellbender, are dull and unattractive. One that most of you have found in the woods, under logs or leaves, is the beautiful little red newt. It has a particularly varied existence. Starting life, as do all amphibia, in a pond or stream, it later becomes land-living. It is in this stage that you find it dressed in red. After a year or two, it returns to the water, regrows gills, and changes to a dull olive-green color. You often find it in this stage, too.



Courtesy Amer. Mus. Nat. Hist.

FIG. 47. The green frog. It can jump fifty times its length. How is it fitted for jumping and swimming?

Tailless amphibia. These are the forms with which you are much more familiar. This group includes the frogs and toads. All of them lay their eggs in fresh water; live for several months, or longer, as tadpoles; then develop lungs and legs. In spite of these organs, the frogs continue to spend at least part of their time under water. Toads, on the other hand, leave the pond. Only in the spring do they journey back to lay eggs. The farther they get away from damp surroundings, the drier does their skin become. Soon it looks shriveled and warty. They can no longer breathe through it as do all frogs and salamanders. But they keep their power of pouring out over the skin a bad-tasting substance which protects them against many enemies. This substance has no effect on your skin. The statement that you get warts from toads was long ago proved to be a myth. In fact, toads are among our most misunderstood friends. They are not only harmless but a great help to the gardener because they rid plants of insect pests. In some European countries they are actually bought to be put into the garden.

At the opposite extreme to the toad is the bullfrog, which rarely comes to land; some have been known to live in wells for years without ever reaching solid ground. To breathe, the bullfrog must, of course, float at the surface, so that its nostrils are above water. Bullfrogs are the largest of the frog family and are as greedy as they are noisy. Insects are hardly worth their while; fishes, smaller frogs, and even an occasional small duckling make up their diet.

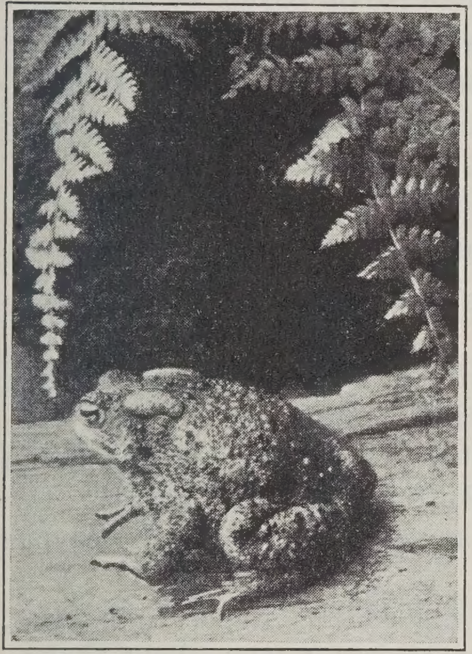


Photo by H. Schneider and J. Schwartz

FIG. 48. The American toad. Compare it with the frog. Which is the better jumper? Why?

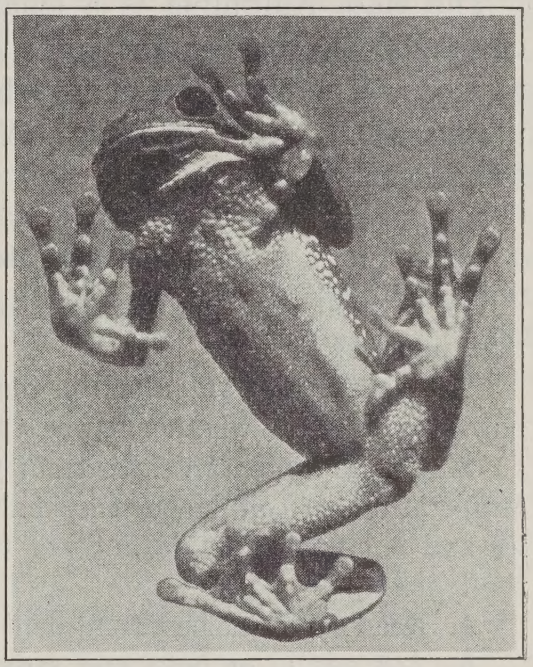


Photo by Hugh Davis

FIG. 49. Giant tree frog. Of what use are the discs on its fingers and toes?

Amphibia as pets. If a frog is given enough water to cover it, some moss or moist soil into which it can creep, and is fed meal worms or other insects, it will live contentedly in confinement and make a very satisfactory pet. Frogs need little space, and are relatively inactive except when escaping an enemy or searching for food. An interesting pet is the little tree frog. It is difficult to see in a tree because of its small size and its color, which matches its surroundings. It is a fearless jumper way above ground and well it can afford to be, for it has a sticky disc under each of its fingers and toes. It often uses its hands to poke food into its mouth. There are tiny tree frogs, no more than an inch or two in length, which gather in the swamps in April and fill the air at dusk with their shrill peeping. They are the "spring peepers" and a welcome sign of spring. You may have mistaken them for birds.

The class Amphibia is a small group compared to the other classes of vertebrates, and, on the whole, of no great importance to man. The last class of vertebrates, still simpler than the amphibia, is the group of fishes. You will become acquainted with them next.

Pupil Activities

1. In what ways are mammals better fitted to spread over the globe than reptiles?

2. If you found an animal in the sea with a body covering of scales, how could you tell whether it was a reptile or a fish?

3. Can you plan an experiment to discover the effects of changes in temperature on cold-blooded animals like the snakes and lizards? Use ice and hot water but do not wet the animal. Why must you change the temperature slowly?

4. Read up on the best treatment for snake bites. Report to the class.

5. Ask adults or boys and girls you know for facts about snakes. Check their statements by using standard reference books. How many of them were accurate?

6. Can you find out whether or not a horsehair put into water will change into a snake? Try it. How often must you do it before you can draw definite conclusions? In this case which is more reliable, your own experiments or some good authority? Explain.

7. Can you think of any reasons why there are so many superstitions about snakes?

8. Are there poisonous snakes in your part of the country? Ask the class secretary to write to the nearest college or zoo to find out. What are they? Where are they likely to be found? How can you avoid being bitten?

9. If you are interested in photography you might try to get shots showing the position of the snake's body and scales when it is moving.

10. Snakes you meet do not pursue you, but if they did could you get away? Explain.

11. Can you build and maintain a miniature reptile house in your school? Collect as many kinds of snakes and turtles as you can find. Baby alligators are often shipped from Florida. But do not collect the animals until you have found out exactly how to care for each of them.

12. Buy a chameleon at some pet shop and study its habits. Can it be trained in any way?

13. If you can find a turtle with a thick shell carve the date and the school number of your class on it. (Ask your teacher to help so that you will be sure not to injure the animal.) Then put the turtle back where you found it. Other classes can search for it each year.

14. What is shown by a closer study of the frog? Study the live frog in a jar of water, large enough to give it a chance to swim. How does it rest; where; in what position? Explain. Which is more motionless while at rest, the frog or man? How does it use its front legs, its hind legs, for swimming? How many joints are there in the legs? Compare with your own. Compare the length of the hind leg with your own in proportion to body size. Study the feet and the "hands." Describe carefully. Do you see any advantage to the frog in what you have just observed? What do you note about the color of the frog? Explain. Study all the organs on the head and describe each. Notice where the eyes are while the frog is at rest. Does the frog have eyelids? Describe and explain what you see. Remove the frog from the jar with your hand. What important observations do you make? Explain. Watch the frog jump. For what purpose does it use each pair of legs? This will need careful observation and probably considerable repetition, before you are sure of your observations. Do they agree with those of your classmates? In what position does the frog keep its hind legs while at rest on land? What is an advantage in this? Does the frog have any other method of locomotion besides swimming and jumping?

15. A terrarium (a home for land-living creatures) may be set up for salamanders, newts, and frogs. Mosses and small ferns will help to make a forest floor.

16. There are so many species of amphibia in this country that an extensive collection can be made almost anywhere. Fruit jars or mayonnaise jars will serve as containers if the tops are sealed with paraffin. Your teacher can show you how to inject formalin under the skin so that your specimens will be well preserved.

17. Frogs and toads make excellent subjects for night photography. Use a flashlight to find them, open the lens of your camera, and then burn a photoflash bulb. The flash lasts about one fiftieth of a second. The lens is closed afterward.

18. For your school magazine write an animal story which would give the reader a good idea of the habits and the personality of a snake, a turtle, a frog, etc. You can do this if you have kept and watched one of these animals closely.

19. *Summary.* Using the facts presented in this chapter, write on the importance of reptiles and amphibia to man. Add more information if you are sure it has been obtained on good authority. State what authorities you consulted so that others can decide whether to accept the information.

Good Books to Read

Barbour, T., *Reptiles and Amphibians.* Houghton Mifflin.
Ditmars, R. L., *Reptiles of the World.* Macmillan. *Snakes of the World.* Macmillan.
Holmes, S. J., *Biology of the Frog.* Macmillan.
Pope, C. H., *Snakes Alive.* Viking.
School Nature League, *The Amphibians. Common Turtles. Harmless Snakes of the N. Y. C. Region. Poisonous Snakes of the N. Y. C. Region. Salamanders of the N. Y. C. Region.* School Nature League, N. Y. C.

CHAPTER V

GETTING ACQUAINTED WITH FISHES

What is a fish? As you turned your eyes from the most complex vertebrates, the mammals, to the simpler ones, you met first the birds, then the reptiles, and most recently the amphibia. There are other cold-blooded vertebrates even less complex — the fishes (*Class Pisces* — pis′ees). No one has any trouble recognizing them; their distinguishing characteristics are a backbone, scales, fins, and gills. (You have seen the gills under the flap on each side of the head.) Since they have gills instead of lungs, they must be water dwellers, obtaining the oxygen they need from the air dissolved in the water. Out of water, fish die quickly because their gills cannot take oxygen from the atmosphere.

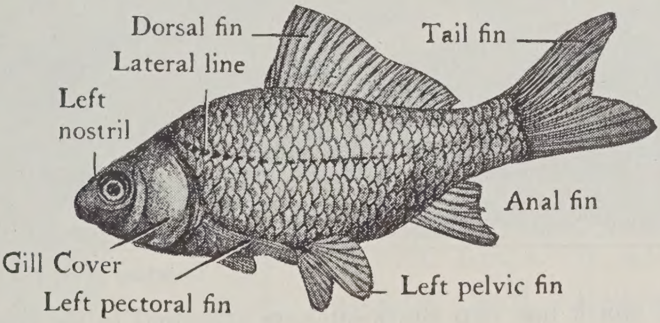
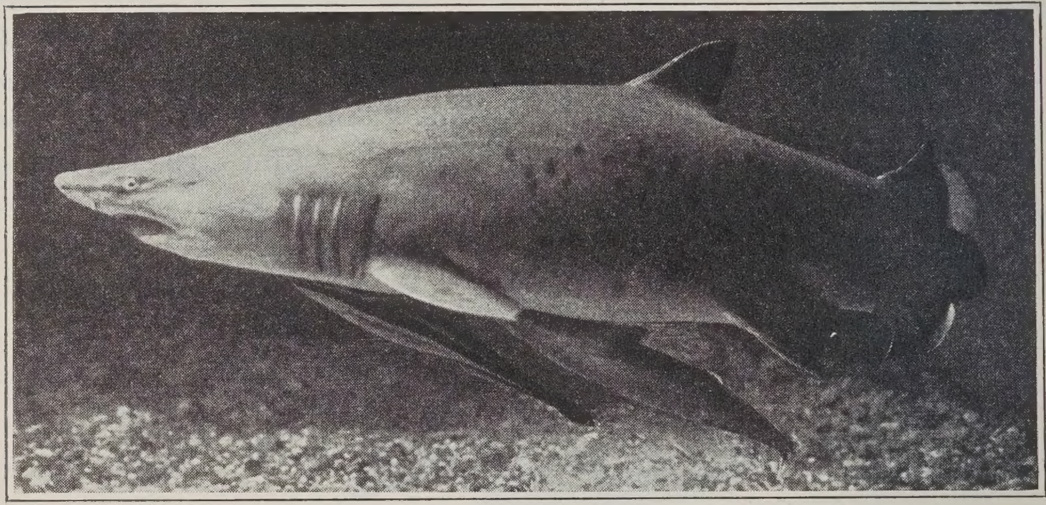


FIG. 50. The goldfish shows the characteristics of all true fish. Where are the gills? How many fins has the goldfish? Compare with other fish.

In place of the arms and legs of other vertebrates, the fish has fins. There is often one pair which corresponds to the arms and another which corresponds to the legs. But the fish usually has other fins which occur singly. These are found in various parts of the body: along the back, on the lower side, and fringing the tail.

"Fish" that are not fish. Most people think of sharks and rays as fish, but the biologist places them in a separate group, lower even than the true fish, because they lack true fish scales and have no real bones. The framework of their bodies is similar to the skeleton of the fish but consists of a softer substance, *cartilage* (car′til-aj). (You may know cartilage by the name of *gristle*—griss″l.) Despite this, the sharks and rays are much like fish in other respects, so they may well be described here.

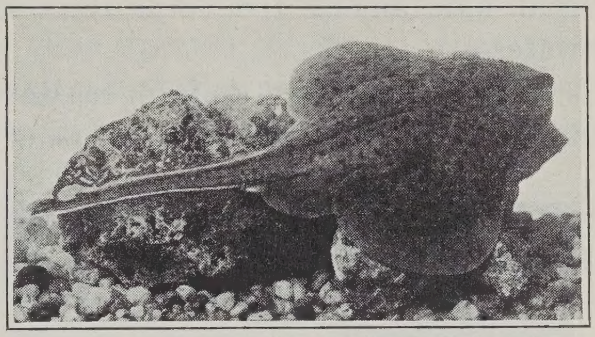
The commonest member of this group is the dogfish that is found along the coast. Fishermen use it for bait; some people eat it but it does not make a well-flavored dish. Sharks are its larger cousins, with reputations often much worse than they deserve. Most species of sharks do not attack men but confine themselves, in their feeding, to fish and other animals of the sea. Although the shark's mouth is on the underside of its head, there seems to be no truth in the belief that it must turn over to bite.



Courtesy New York Zoological Society

FIG. 51. This shark has two shark-suckers attached to its lower side. What differences do you note between the shark and the true fish?

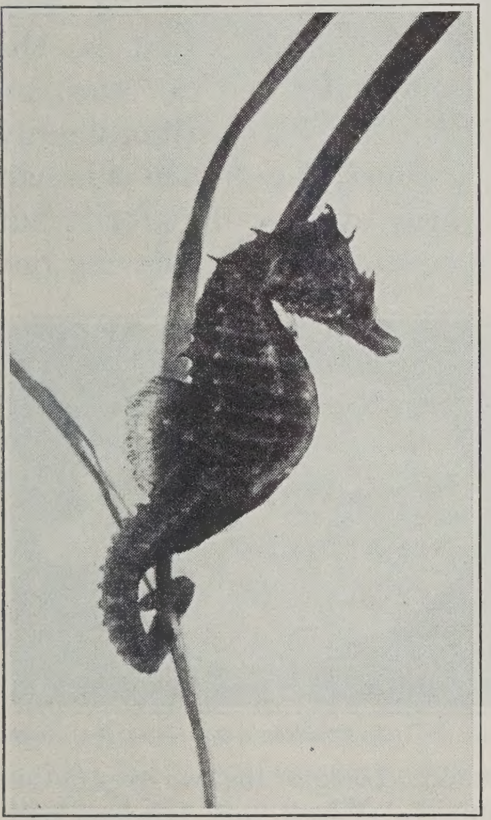
The rays and skates are much-flattened, queer looking creatures. They have a bad name among fishermen — "devilfish." (Not to be confused with the devilfish of which you will read later.) They are generally smaller than sharks but may also reach an enormous size. Specimens measuring twenty feet in width and weighing more than a ton have been caught. The ray and skate rest on the ocean floor where they feed. They swim by means of graceful flapping movements of their "wings," which take the place of the powerful tail of the shark. One of the rays is the long, much-flattened sawfish. This animal carries a five foot double-edged saw at the front of its head. With this it can deliver swift sidewise strokes.



Courtesy N. Y. Zoological Soc.

FIG. 52. Like the shark, the skate has its mouth on the lower side.

The vast number of fish inhabiting this earth. There is three times as much sea as land and the average depth of the ocean is two miles. You can see that there is plenty of room for fish; and they make the most of it. They swarm in warm waters and in cold; even the arctic seas have fish. Some kinds swim at the surface, others at the lowest depths. They are incredibly numerous, being hatched and killed in numbers too great to grasp. It is estimated that at present there are almost two billion people in the world. But that is a tiny number compared to fish populations. Of the herring alone, man catches and destroys about eleven billion each year. Yet this is a small part of the total number killed. It has been estimated that 200 billion other herring perish yearly, eaten by larger fish. And the ocean remains well stocked with herring.

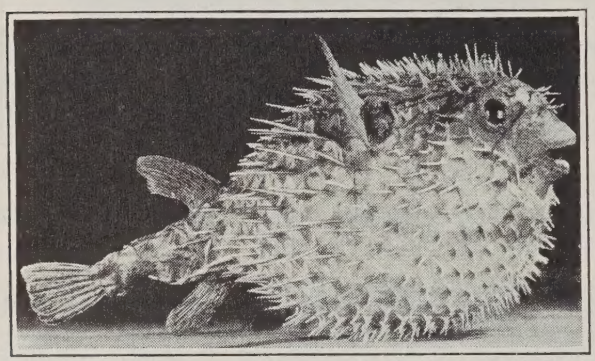


Courtesy N. Y. Zoological Park

FIG. 53. The sea horse swims in this position. Of what use is the tail when the fish is at rest?

The variety of fish. Fish are as varied as they are numerous. Twelve thousand different species have been described, most of them salt water forms. They may be of almost any color: lemon yellow, orange, red, green, bright blue, or they may show combinations of different colors in complicated designs. The most brilliantly colored are those that hide among the coral reefs and seaweeds of the tropical waters.

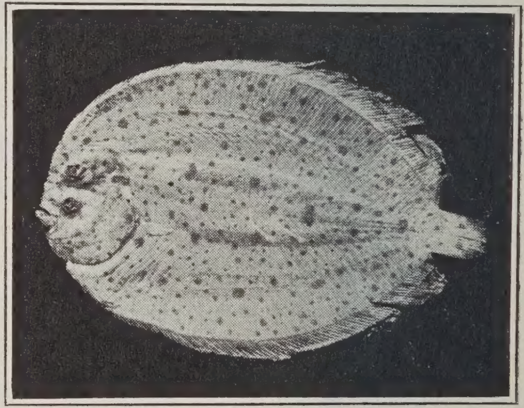
Fish are no more uniform in size than in color. A good-sized tuna fish weighs three quarters of a ton; the guppy of your aquarium measures a scant inch and weighs so little you could not feel its weight in your hand. While most of them are formed like a boat for cutting the water easily, some have the most unexpected shapes, as the pictures show.



Courtesy N. Y. Zoological Park

FIG. 54. The porcupine fish when blown up as in this picture floats at the surface.

Some interesting fish. The flatfish, that is, the flounder and the soles, are curiously built to suit the life they lead. They are extraordinarily flat from side to side and spend their time lying on one side half buried in the sand. When food is near by they dart for it but promptly go back to their hiding places. Instead of having one eye on each side of the head they have both eyes on one side, the side which is always up. They are not born this way, however. Their eyes, at first, lie where you would expect them to be, one on each side of the head. Then one eye moves around to join its mate. As the young fish develops, the eye can be seen to change its place. This is advantageous to the flatfish since an eye on the underside would be useless.

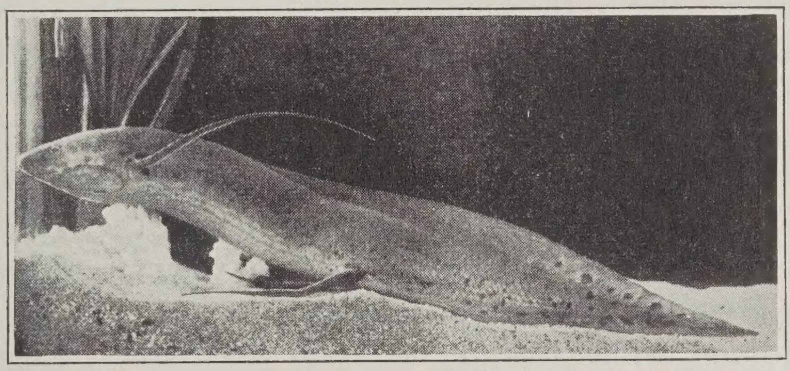


Courtesy Amer. Mus. Nat. Hist.

FIG. 55. Look for the two eyes in this flounder. Where must the backbone lie?

You may have heard of "flying fish" but fish cannot really fly. All fish, when swimming rapidly, push themselves through the water entirely by means of their muscular tails. When near the surface this motion of the tail may drive them out of the water, so that fish are often seen jumping. Now the flying fish have very long paired fins which they are in the habit of spreading as they leave the water. Thus, they glide through the air. If they get a good start they can glide above water for as much as an eighth of a mile. Of course they do not flap their fins; they hold them rigid, as the hawk holds its wings when it soars.

The remoras (rem′o-ras) have developed a different mode of locomotion. They travel about by stealing rides. Provided with a suction plate on the top of their heads, they attach themselves firmly to a shark's belly and loosen their hold only temporarily as they dart after remnants of food left by their host. Curiously enough, the shark does not seem to begrudge its riders either the free transportation or the meal.



Courtesy Amer. Mus. Nat. Hist.

Fig. 56. The lungfish has paired fins which are whiplike. Where are they situated?

Interesting in another way are the grunts and the sea drums, the noisy members of the class. Although most fish are probably totally silent, these animals can make noises. There is reason to believe that fish can hear, despite the lack of outer ears.

Among the strangest fish are those that can breathe by means of lungs. This sounds as if they could not be fish, but they have gills just as all fish should have. Every fish has an air bladder which by becoming larger or smaller helps it to rise and sink. In the lungfish the single air bladder is replaced by two air bags which are connected to the throat so that air can be taken in. Lungfish live in swamps and drying pools in which gill-breathing fish would die of suffocation. When the pools dry up completely the lungfish burrow in the mud, coil up in a chamber with a hole, and remain alive until it rains again. There is one fish, the mud skipper, which has developed into a true air dweller.

Fish migration. Fish migrations are as interesting and as puzzling to the biologist as are bird migrations, and, naturally, much more difficult to study. For some unknown reason reproduction among some fish occurs far from their native haunts. Although the eel had been known and caught as a food fish for thousands of years, until twenty-five years ago no one knew where it laid its eggs and reared its young. Each fall thousands of mature eels were seen to swim down the fresh water streams of Europe and America into the Atlantic Ocean. There they disappeared. Finally a scientific expedition tracked them to a region east of Bermuda, where, a mile down, they lay their eggs. Then the parents die. The young fish remain near their breeding place for a year, then begin the long journey back to the homes they have never seen in the rivers of the two continents. The American eel turns toward the rivers of our country; its European cousin travels eastward. It may take several years before they reach the streams which had been inhabited by their parents; but without assistance, journeying through waters they have never been in before, they finally reach their destination. When they are mature, they swim back to the breeding grounds in the Atlantic Ocean.

The salmon, which live in the ocean when adult, migrate into fresh water at spawning (egg-laying) time. They swim far up into the shallow headwaters. Here the eggs are laid. Then most of the parents die. The young develop slowly and eventually swim out to the sea, where they remain until they are ready for spawning. Within the last few years much has been learned about the migrations of fish by the United States Bureau of Fisheries. Thousands of fish are tagged with a small numbered plate which fishermen are asked to return with information as to the size of the fish and the place where it was caught. By recording all these facts carefully, biologists are learning more about the habits of fish and the places to which they go.

Pupil Activities

1. Study of a living fish. Examine a goldfish in a bowl of clear water. Where are the paired fins? Where are the unpaired fins of the goldfish? Which is the largest fin? Examine a fin while it is spread out. What is its structure? How is it fitted for its work? How are the scales arranged? Is this of any advantage to the fish? Try to catch the fish with your hand. What do you notice? Describe the movement of the gill cover. What do you see underneath it when it lifts?

2. Stir the water in the goldfish bowl to make the fish swim quickly. What enables the goldfish to move through the water? What part do the paired fins play in locomotion?

3. Look up "sculling," a method of moving a small boat through the water. How is it like the swimming of a fish? How different?

4. State at least four ways in which the fish is particularly well fitted for rapid movement through the water.

5. Use a college textbook of zoology (the study of animals) to find out how sharks and rays differ from true fish. Prepare a short talk to your class explaining how they are classified.

6. Have you ever maintained an aquarium of tropical fish? If you have, report briefly to your class on their structure and habits.

7. If you can, examine a whole flounder or sole at the fish store. Of what advantage to the fish is the "pepper and salt" coloring of the upper side? What is the shape of the mouth?

8. Look up lungfish. Tell your classmates why the biologist considers them important.

9. If you know an expert fisherman, ask him to tell you something about the habits of the game fish he has attempted to catch.

10. Do brook trout migrate? How could you find out?

11. Organize a class trip to a fish market on a Thursday afternoon after school. What kinds of fish do you find? List them. Take notes on their sizes, colors, and markings so that you can recognize them again. How much do they cost per pound? Compare the price with that of lamb, chicken, beef, and pork. Why can fish usually be sold more cheaply than meat?

12. The *National Geographic Magazine* can supply you with many interesting articles on fish. Look up in a library or in secondhand book stores. The address of the National Geographic Society is Washington, D. C.

13. *Summary.* Answer these questions: How can you tell that an animal is a fish? What are the chief kinds of fishes? What are some important facts about fishes?

Good Books to Read

Eifrig, C. W. G., *Our Great Outdoors; Reptiles, Amphibians and Fishes.* Rand McNally.
Fleuron, S., *Grom, the Story of a Pike.* Knopf.
Fuller, R. T., *Along the Brook.* John Day.
Innes, W. T., *The Modern Aquarium.* Innes.

Jordan, D. S. and Evermann, B. W., *American Food and Game Fishes.* Doubleday.

Mellen, J. M., *Young Folks' Book of Fishes.* Dodd Mead. *Fishes in the Home.* Dodd Mead.

National Geographic Society, *The Book of Fishes.*

Norman, J. R., *A History of Fishes.* Stokes.

Roule, L., *Fishes, Their Journeys and Migrations.* Norton.

Williamson, H., *Salar the Salmon.* Little, Brown.

CHAPTER VI

THE INSECTS

Animals without backbones. The animals you are to learn about in the following chapters are built on a plan different from that of the animals you have met so far. They have no internal skeleton; there is nothing in the body like a backbone or skull. Whatever skeleton they may possess is either on the outside, like a coat of armor, or is so different from the skeleton of the backboned animals that you would never confuse the two. You have already learned the name vertebrate for the backboned animals; the name *invertebrate* is used for the animals which lack a backbone.

You must not forget the fact that all the backboned animals, fish, amphibia, reptiles, birds, and mammals, are members of one great group or phylum, the phylum Vertebrata. Despite their familiar differences all these animals are so much alike that they are put into one phylum. But the animals without backbones, the invertebrates, show such great variety of structure and habits that biologists assign them to many different phyla.

There are from fifteen to twenty times as many species among invertebrates as among vertebrates. Exact statements cannot be made because no one can easily list all the names of species and count them. If that were done it would not help much either because new species are constantly being discovered, described, and named. However, one biologist has estimated that there are no more than 40,000 species of vertebrates and almost 800,000 species of invertebrates.

The most complex invertebrates. (*Phylum Arthropoda* — Ar-throp′o-da.) This is a large phylum consisting of many species with which you are familiar. It includes all the invertebrates with jointed legs, hence the scientific name Arthropoda (jointed feet).

The animals included in this phylum have an external (outside) skeleton. It is not made of bone or cartilage, but largely of a material called *chitin* (ky′tin). The legs and feet, as you have read, are jointed. In fact these two characteristics, the hard outer skeleton of chitin and the jointed legs, enable you to recognize an arthropod (ar′thro-pod) easily.

If you begin to think over animals that meet this description of arthropods, one form that may come to your mind is the grasshopper, or, if you live near the seashore, the lobster or crab or shrimp. These and many, many others belong to the phylum Arthropoda. But grasshoppers and lobsters differ from one another, too, and for that reason grasshoppers are put into the class *Insecta* (in-sek′ta) and lobsters are put into another class.

How can you recognize an insect? Some of the characteristics of insects are known to you already. They are animals (animal kingdom); they are invertebrates with an exoskeleton or hard covering and jointed legs (phylum Arthropoda). But they also have special characteristics which lead biologists to separate them from other arthropods. One such characteristic is the possession of six legs. Another is the division of the body into three parts: a *head*, a *thorax*, and an *abdomen* (ab-doh′men). These parts are easy to distinguish when once you know that the thorax is the middle section, the part which has three pairs of legs attached to it. In front of it is the head; you can tell it by the eyes and the feelers, or *antennae* (an-ten′nee). At the other end of the thorax is the abdomen which is made up of clearly seen rings (*segments*). The abdomen never has legs. But until you look closely one pair of legs may seem to be attached to the abdomen. If you do find legs on the abdomen, you may be sure that the animal is not an insect; it is some other kind of arthropod.

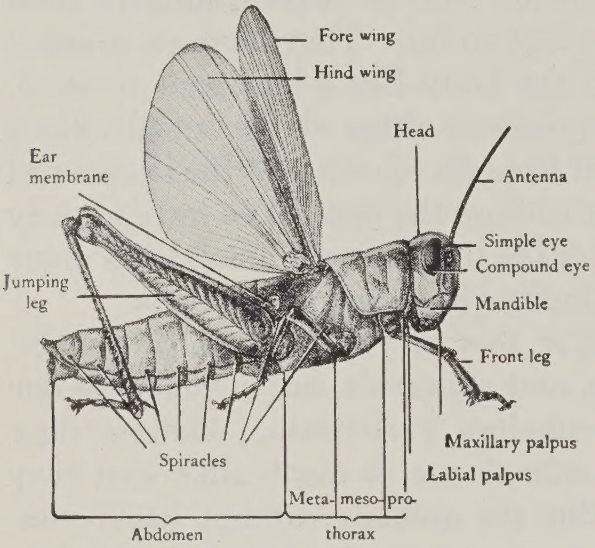


FIG. 57. The grasshopper is an example of the insect group. The appendages of one side only are shown. How many are there of each kind?

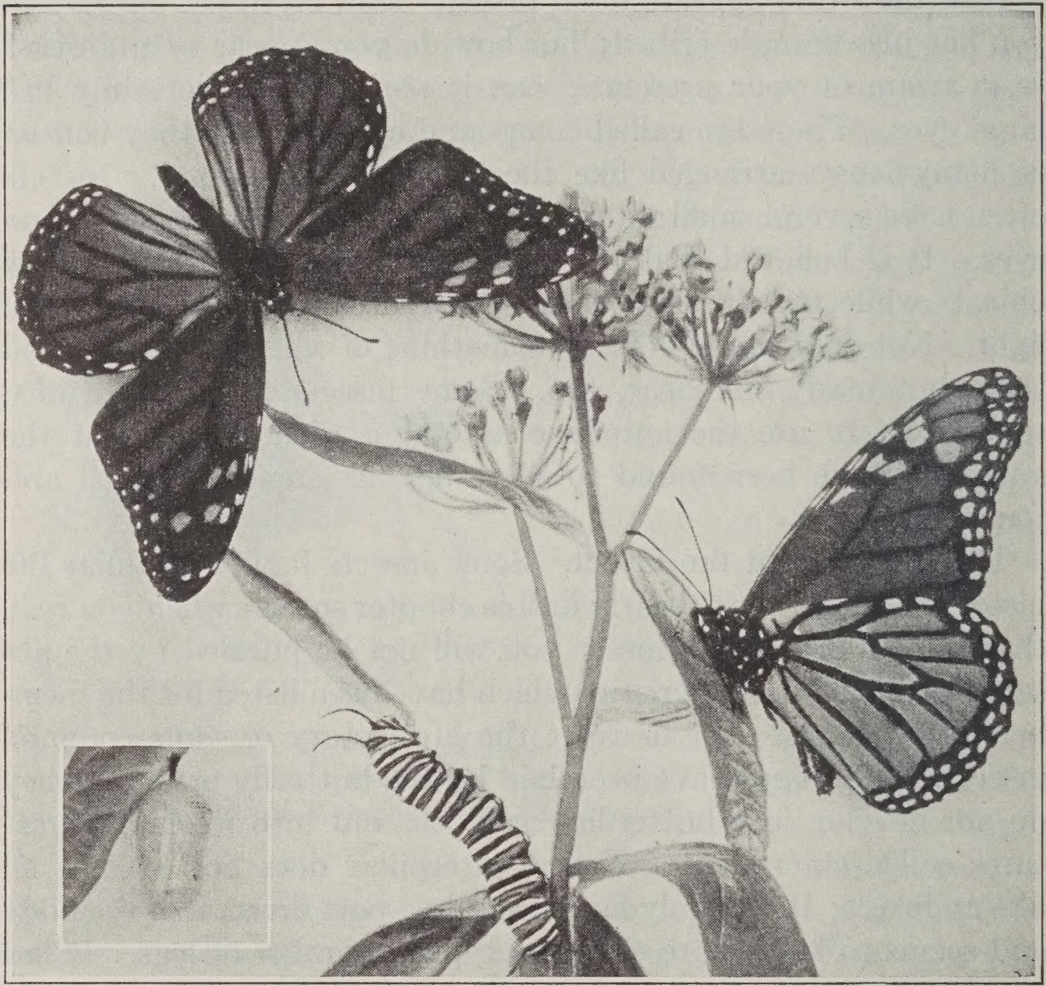
The typical insect often has another striking characteristic. It has two pairs of wings. But there are many that have only one pair and some that have none at all, so that you cannot depend on the presence of wings as a way of recognizing insects. The wings, legs, and antennae may be referred to as *appendages* (ap-pend′-a-jes), which means structures "hung on" to some part of the main body.

How the world appears to an insect. How an insect appears to you has just been described; but how do you appear to an insect? Is it aware of your presence; can it see you? It certainly has large eyes. These are called compound eyes because they consist of many lenses arranged like the facets of a diamond. Insects often have several small, simple eyes besides the pair of compound eyes. It is believed that the compound eyes observe motion of objects while the simple eyes see differences in the brightness of light. Not only can insects see something of what goes on around them but many can hear, too. Some insects have ear drums; some seem to use the antennae as organs of hearing. But the antennae have been found to serve also as organs of smell and touch.

The life story of the insect. Some insects have a peculiar life history; it must be told early in this chapter so that when you read that some animal is an insect you will not be puzzled by the absence of all the characteristics which have been listed for the members of the class. Let us trace the life history of some common insects. After eggs have been laid by the butterfly or moth, they do not develop into butterflies or moths but into wormlike creatures called caterpillars. Now a caterpillar does not look at all like an insect; it certainly lacks the three-part division of the body and seems to have more than the typical number of legs. It has no wings and no antennae. After a period of steady feeding either it forms a hard protective coat or it builds a little house around itself, a cocoon (kuh-koon′). This may be made of a dead leaf or of threads spun by the caterpillar. Protected in this way it changes itself over. When it comes out it is a butterfly or moth. These insects, therefore, go through a life history in which they are first in an egg stage, then in the caterpillar stage, called the *larva*, then in a changing-over stage, called the *pupa* (pew′pa), and, finally, adults like their parents. Sometimes the insect spends practically its whole life in the first three stages; some species of mayflies live as adults for only one day!

There are many insects that do not have so complicated a life history; they have only three stages instead of four. This is true of the grasshopper, as you will read later.

Insect flight. Insect flight differs from bird flight because the two kinds of animals are so different in size and structure. The body of the flying insect is usually much smaller in proportion to the wings than is the body of the flying bird. The wings of the insect are thinner and lighter, since they contain none of the flesh and bones which make up the wing of the bird.

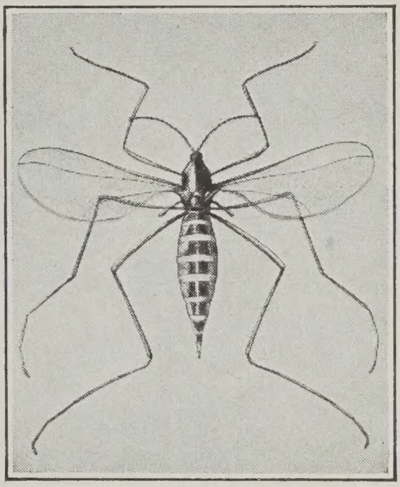


Courtesy American Museum of Natural History

FIG. 58. Three stages in the development of the monarch or milkweed butterfly are shown. The hard coat of the changing-over stage is called a chrysalis. What stage is missing?

The most extraordinary fact about insect flight is the rapidity with which some insects move their wings. The cabbage butterfly is a slowpoke; it beats its wings only nine times a second. A wasp moves its wings more than ten times as fast. A still more amazing speed is displayed by the housefly whose wings make 330 movements a second, 19,800 times a minute! Is it astonishing that you hear a loud buzz when a fly is near you or that you cannot see the movement of its wings?

This extreme rapidity of wing movement does not mean that the insect flies at high speed. Grasshoppers have been timed by men in automobiles who followed a single insect while watching the speedometer. Apparently, twenty miles an hour was the top speed. The "darning needle," however, can fly almost ninety yards in three seconds. If it could keep up this flight its speed would be sixty miles an hour. Insects, so far as is known, cannot fly great distances without stopping. Those insects that migrate do so in many short stages.



Courtesy U. S. Bur. Entomology

FIG. 59. The Hessian fly is a dreaded destroyer of wheat. Its larva sucks the sap. Can you find the halters that take the place of the second pair of wings?

The roll call of insects. It would take a long time to call the roll of insects: about 600,000 would have to answer to their names. When there are so many species you can guess that they must be grouped in many different orders. Their classification is extremely complicated. No attempt will be made to give it here. Yet many insect types are familiar to you because wherever you may live, insects are so common. All of you know flies, butterflies, grasshoppers, bugs, beetles, ants, and many others.

The two-winged insects — flies. (*Order Diptera.*) A common example of this order is the housefly, which nowadays is often called the "typhoid fly." Close relatives are the black flies that are found in the north woods and which draw blood when they "bite"; the blow flies that injure cattle; and the Hessian flies which got their name because they appeared in this country shortly after Hessian soldiers came over during the Revolution. The mosquitoes and the gnats or "midges" belong to this order, too. There are many other kinds less familiar to you. They are different from other insects in having only one pair of wings, and stumps in place of the second pair.

One fly which has become of enormous importance is a harmless and tiny creature that eats yeast plants growing on fruit. It is commonly called the fruit fly or vinegar fly; it is important because biologists use it for experiments. You have often seen it hovering about a plate of fruit. It looks like a "baby fly." But, of course, it is not a baby fly which will grow larger. A young fly, just hatched from the egg, is a larva without wings or legs, called a maggot. The little fly appears after the pupa stage but no little fly ever grows into a larger fly.

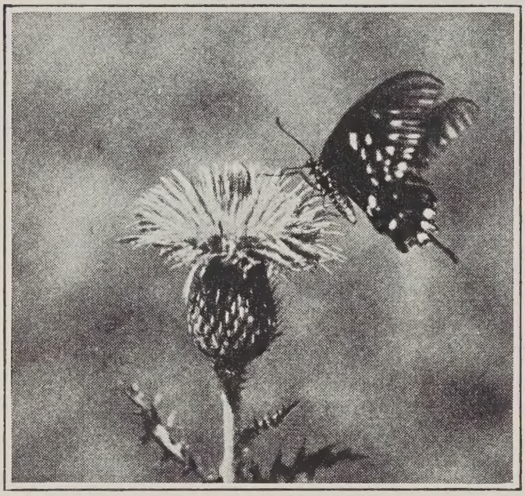
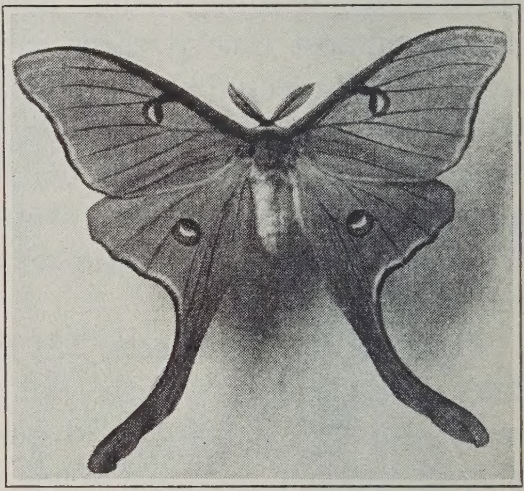


Photo by H. Schneider and J. Schwartz

FIG. 60. A swallowtail butterfly on a thistle. Give three reasons for calling it a butterfly.

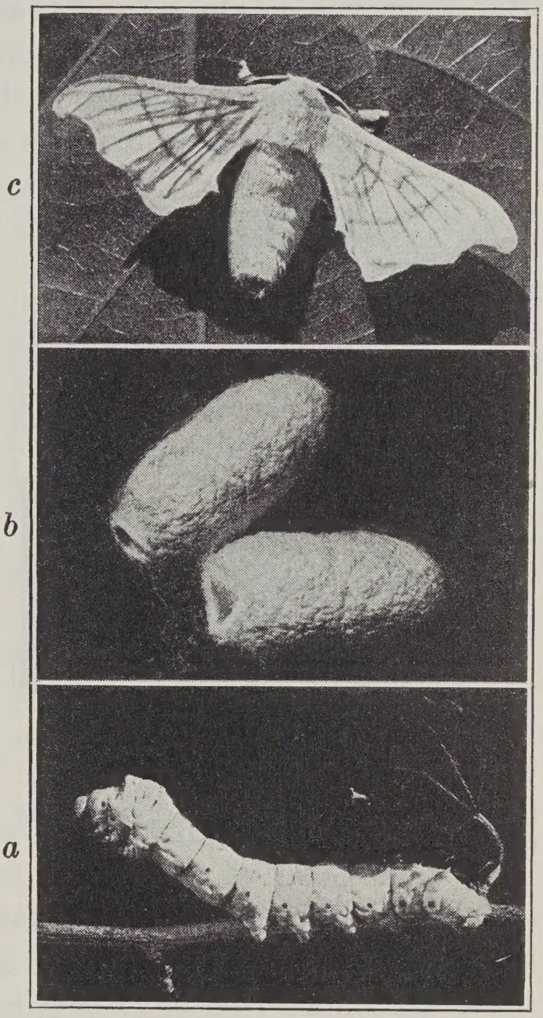


Courtesy U. S. Bur. Entomology

FIG. 61. The Luna moth is known also as the Pale Empress of the Night. Its color is pale bluish green.

Insects with scaly wings. (*Order Lepidoptera.*) This group is well known, too. It includes moths and butterflies, insects that have large wings covered with tiny scales. These scales are often brightly colored and may be arranged in gay patterns. They are loosely attached, as you know if you have ever handled a butterfly. If you use a microscope you can see that the "powder" that comes off consists of scales. The differences between moths and butterflies are not hard to learn. The bodies of moths have much more "hair" on them than have those of butterflies; their bodies are also heavier and more clumsy. The "feelers" or antennae of moths are "feathered"; the butterfly's are smooth and sometimes knobbed at the tip. And if you watch the two when they alight you will detect another difference; the moth spreads its wings flat when resting, the butterfly holds them upright.

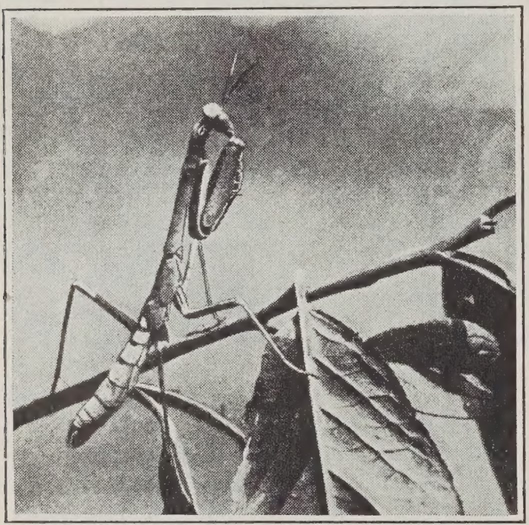
Butterflies are day fliers but toward evening you will see moths, perhaps the Luna or Cecropia, or close relatives. These giant moths are among the most beautiful of the insects and also among the largest. Their wingspread may be as much as six inches. They are closely related to the smaller silkworm moth which for more than four thousand years has supplied man with silk. During all these ages silkworm moths were reared in China, where they were tended as carefully as the larger domesticated animals. The moths lay their eggs on mulberry trees which are specially planted for the purpose of supplying food to the young when they hatch from the egg. The tiny caterpillar or "silkworm" feeds and grows. It lives as a caterpillar for a month and a half. Then it spins a cocoon out of silk threads. These threads come out of its body as a liquid which hardens in the air. The silkworm goes on spinning until about a thousand feet of thread are wound about itself, woven into the golden-yellow cocoon. Before it has time to change into the adult moth the silk grower kills the insect in its house and unwinds the silk. This is done by hand and takes a long time. Of course, some of the silkworms are allowed to develop into moths; the moths are guarded carefully and allowed to lay eggs for the next batch of silkworms.



Courtesy Amer. Mus. Nat. Hist.

FIG. 62. *a.* The Chinese silkworm clinging to a twig by its hind end. *b.* What do the holes in the cocoons tell you? *c.* How do you know that the adult is a moth and not a butterfly?

Other moths of medium size are the hawk moths. Their wings are long and narrow so that as they hover over a flower and beat their wings rapidly they may be mistaken for hummingbirds. But when you catch one and examine it you will see that, like all its relatives, it has two pairs of wings covered with scales. These are not always bright in color but they show striking designs. The large, smooth caterpillar has a habit of rearing up in front. In this position it resembles the famous Sphinx. So these insects are also called Sphinx moths.



Courtesy U. S. Bur. Entomology

FIG. 63. The praying mantis is a useful insect. Why was it given this name?

At night various moths may come indoors because they are attracted by the bright glare of artificial light. But only one of this group of insects really lives indoors, the ragged little clothes moth.

Grasshoppers and their relatives. (*Order Orthoptera.*) The grasshopper group includes the crickets and katydids of noisemaking fame. It includes also that champion of eaters, the praying mantis. Ferocious as the praying mantis looks you need not be afraid of it, for it will not harm you. It is the grasshopper that may well be in fear, for off comes its head when the mantis catches it.

Most of the insects of this group have a pair of wings which can fold up like a fan. When not in use they are tucked away under the first pair of wings, which are stiff. This pair does not help much in flight but serves to protect the lower wings against injury from sticks and stones and vegetation. Since these insects live chiefly on the ground their wings need protection.

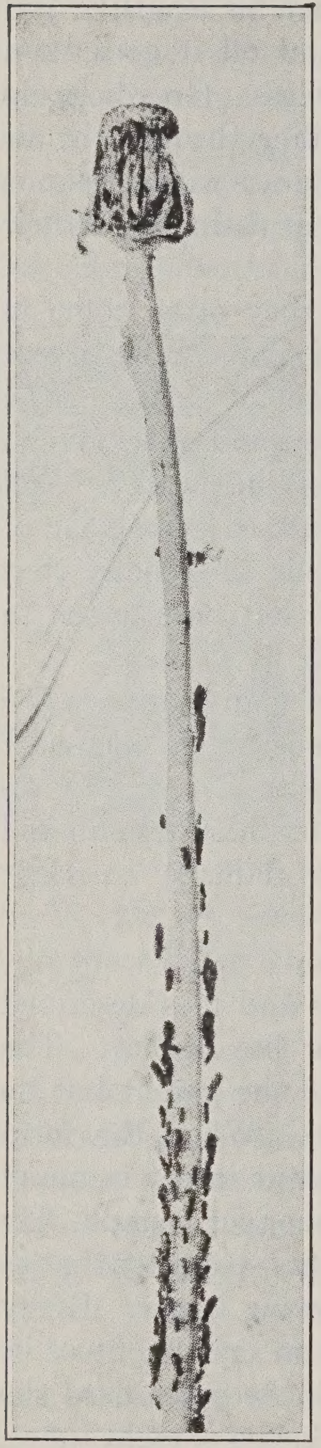
Grasshoppers or locusts are always lively insects, trim in appearance and well-groomed, with big eyes and serious faces. They are equipped with strong muscular hind legs which enable them to perform the most amazing jumping feats. A grasshopper is capable of a standing broad jump fifty times the length of its body, while man's latest Olympic record is only about twice his length! And the instant the grasshopper strikes the ground off it goes on a second leap and a third. Its muscles seem tireless. Grasshoppers are fascinating to watch, whether jumping, sailing through the air with outstretched wings, crawling up a stalk of grass with antennae waving to sense the first approach of danger, or eating with their sidewise moving jaws.

Singly, grasshoppers do little harm. But they often come in vast numbers. Carried over long distances on some strong breeze of which they take advantage by using their membranous wings, they arrive in thousands and hundreds of thousands. They can be seen approaching as a threatening dark cloud in the sky. And when they settle on the fields, they eat one stalk of grain clean of its leaves, then hop to the next. They do this so steadily that every bit of vegetation disappears; fields are left bare, often to the ruin of the farmer.

Such plagues of "locusts" have occurred in many lands. The children of Israel departed from Egypt because of a plague of locusts. Egypt is still in constant fear of them. They have appeared in our own country. The Rocky Mountain states suffered in 1931 when locust plagues caused great damage to their crops.

Grasshoppers and all their close relatives have a life story different from that of the butterflies and moths and flies described above. They have only three stages in their life history. The animal that comes out of the egg is much like the parent but its proportions are different and it lacks wings. When the form which hatches from the egg resembles the parent insect in many ways it is called a *nymph* (nimf). The grasshopper nymph, like the adult, is encased in a coat of armor. This fits so tightly that as the grasshopper eats it is prevented from growing larger. Every once in a while it splits this outer skeleton and crawls out of it. This is called *molting*. Before its new skeleton becomes hard the insect grows rapidly. This occurs as many as seven or eight times, during which period its wings appear and the body proportions change. After that it is full grown.

Cockroaches belong to this group, too. Although unpleasant creatures, roaches are interesting to study. In many species it is only the females that have wings, and then only at certain periods



Ill. Nat. Hist. Survey

FIG. 64. Aphids on the stem of a dandelion.

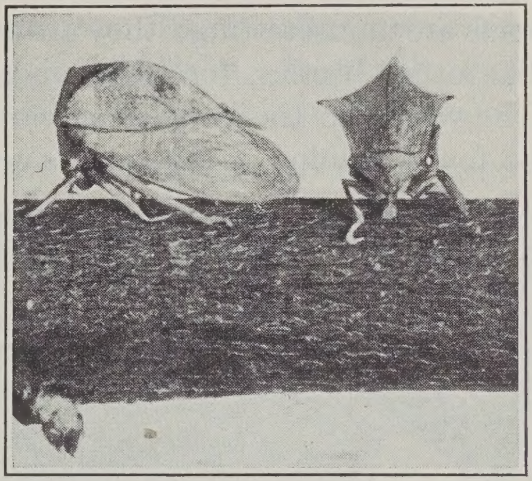
of their lives. Cockroaches lack large hind legs for jumping. But they can run, as you may know, with great speed. Their bodies are so flattened that they can crawl through narrow cracks. They prefer the shelter of a house where they go prowling about at night in search of crumbs. In warm tropical climates they are a greater pest than they are here.

Bugs. (*Order Hemiptera.*) Many people call all insects "bugs." This is a poor name because there is one special group of insects which is scientifically known as bugs. It is a group with which, for the most part, you do not want to have much to do. It includes the plant lice or *aphids* (af′fids), soft-bodied insects which cling tightly to plants and suck their juices. What aphids lack in size they make up in numbers. They reproduce at such a rate that shortly after they have arrived on a plant they may completely hide the stem. They are a nuisance to everyone who tries to raise plants indoors or out. Closely related to aphids are the scale insects which attack our fruit trees and multiply into millions, too. They cover themselves with tiny scales like shields; thus protected, they feed on the sap and make more of their kind.

Other true bugs are the lice, which live on birds and mammals. The fleas and bedbugs are true bugs, too. Most of these insects feed on blood.

There are larger bugs, too. You would never suspect the "seventeen-year locust" of being a bug. The young, soon after they have hatched from the egg, fall to the ground and dig into the earth. There they live for seventeen years preparing to be adults! When they do grow up and come up out of the ground as big, clumsy, winged insects, they live only a few days. They make the most of these, singing shrilly when the day is warm.

Other bugs live in the water. You have seen spiderlike creatures with long legs outstretched darting about on the top of the quiet water in some back-eddy of a brook. They are well named waterstriders, for they actually walk on the water. Their legs are covered with hairy structures and the thin surface film of the water is sufficient to support the insect, whose body is extremely light. Other bugs which cannot skate over the surface swim near the top. The water boatman has two pairs of legs that look like oars. Some bugs swim on their backs, which are shaped like the keel of a boat. These backswimmers, though only a quarter to half an inch long, are ferocious little creatures which will attack even man with their tiny beaks.



Courtesy U. S. Bur. Entomology

Fig. 65. The buffalo tree hopper is about $\frac{1}{3}$ of an inch long. It is found in many parts of the country. How did it get its name?

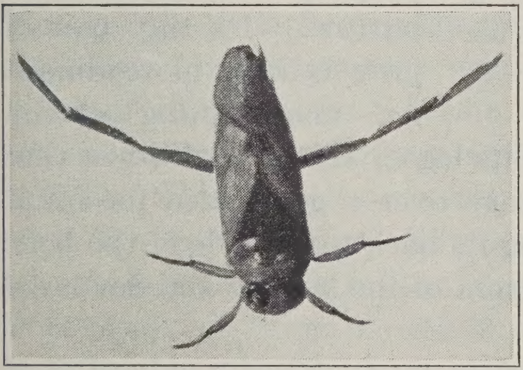


Photo by Cornelia Clarke

Fig. 66. How is this backswimmer fitted to move itself through the water?

Insects with many tricks — beetles. (*Order Coleoptera.*) All beetles have hard wing covers which completely cover the upper side of the abdomen and fit so closely that you can scarcely see the seam down the middle of the back. It is always a surprise to see the back split open when the insect takes to flight. The ladybird beetle, the famous "ladybug, ladybug, fly away home," is a good example of the group. Many beetles have even brighter colors and more striking designs. Another beetle everyone likes to see is the firefly whose light goes on and off like a tiny flashlight as frequently as once every second or even faster, and sometimes with great regularity. It keeps its light on the lower side of the abdomen. In the daytime these insects are uninteresting; they are dull colored and they are not trim like other beetles, for their wing covers are not firm and hard. The young, in the larva stage, are called glowworms. They can be found shining in the grass, since they have no wings for flight. If you can collect half a tumblerful you can get enough light to read by.

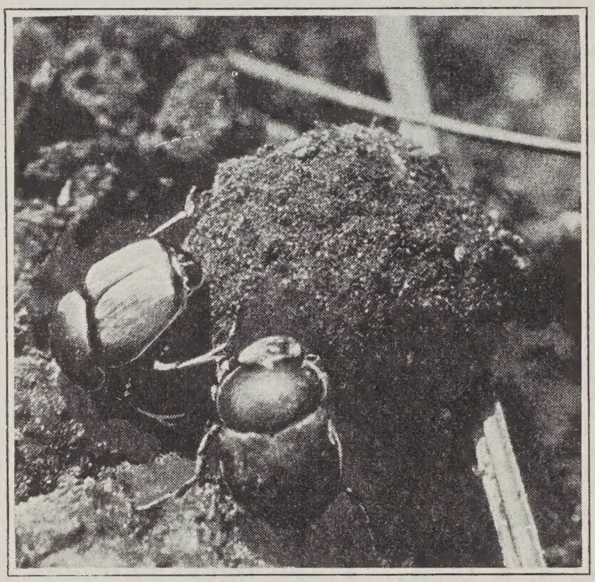


Photo by A. L. Melander

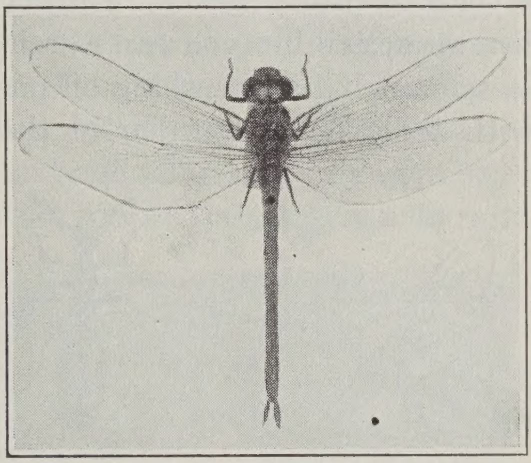
Fig. 67. The dung beetles collect manure or dung, roll it into a ball, and push it along from place to place. They may use it as food or the female may place an egg in it.

Very common are the tiger beetles, whose metallic green or shiny bronze coats may be seen on dusty roads or in fields. The young of this beetle is an ugly wormlike larva with vicious jaws. It digs deep burrows in hot, sandy places. Then it rests near the top of the hole, twisted so that its head neatly plugs up the entrance to its burrow. Its tiny pair of jaws is kept in readiness. An unsuspecting victim passing near the hole is seized by its legs. In the tug-of-war that follows the larva has an advantage over a good-sized foe for it keeps itself well braced by hooking its back to the side of the hole. The victim is dragged to the bottom of the burrow and devoured at leisure.

The bombardier beetles are also common. They bombard their enemies with several shots of liquid that go off with a loud noise. The liquid at once changes to a gas and while the smoke screen lasts the bombardier beetle scurries away to shelter. The click beetles try another trick. You may have seen them lying on their backs as if they were dead. But suddenly when all danger is past, you hear a sharp click and the "dead" beetle has clicked itself into the air where it turns over, lands on its feet, and runs away. They are long, flat beetles, sometimes an inch in length, dull in coloring but often with two enormous black marks that look like eyes on the thorax.

This group has its water dwellers, too. The whirligig beetle is as good an acrobat as the click beetle, in its way. It gets its name from its habit of swimming in circles on the surface of the water. Whirligigs are usually found whirling around in large numbers.

Insects that haunt the water. There are many insects that lay their eggs in water but one group with which everyone is familiar is the group of dragonflies. The large bulging eyes which cover the head and the long narrow abdomen which it swishes about in its rapid flight, make it a terrifying object. Sometimes it is called the darning needle because its body is so long and thin. It is quite harmless; in fact it is one of your best friends. As it darts through the air above some quiet pond it is catching and eating mosquitoes.



Courtesy Amer. Mus. Nat. Hist.

FIG. 68. The dragonfly or darning needle is one of the fastest of insect flyers. How does that help it to get its food?

Insect communities. While most insects live solitary lives, certain kinds live in large groups. The ants, the bees and wasps, and the "white ants," or termites, live in large communities somewhat like those man has developed. Each insect has some special job which it performs for the benefit of the community at large. A close study of these insects is always fascinating; whole books have been written on the lives of a single species of ant or bee.

Of all the *social insects* (those that live together in communities), the ants, which are found in almost every part of the world, are the easiest to study. Most of you have had the experience of turning over a rock to discover an ant nest beneath it. You may have seen the ants pick up large white bundles, run back and forth in great excitement, and finally dash off to some safe hiding place. Then they come back for more bundles until shortly the nest has been cleared out. You may have heard these bundles called ant eggs. Of course, you know that they are much too large to be eggs; they are the pupae which are almost ready to become adult ants. Most of you, too, have seen in fields, or at the edge of the forest, mounds of earth with many ants scurrying about. These ant hills may be two or three feet in diameter and may house several thousand insects. During the warm months when the ants live an active life you can watch them climbing out of tiny holes in the ant hill and rushing off on their business. Others, perhaps with some heavy burden in their jaws, crawl down the holes. Close observation may show fresh grains of earth piled up around the entrances and, with patience, you may see an ant appear from below, put down the soil it has been carrying in its jaws and quickly disappear again into the nest. This is particularly common in the spring when the ants seem to be opening house. There is constant coming and going; something is happening all the time. If you watch them you can discover what jobs they are doing.

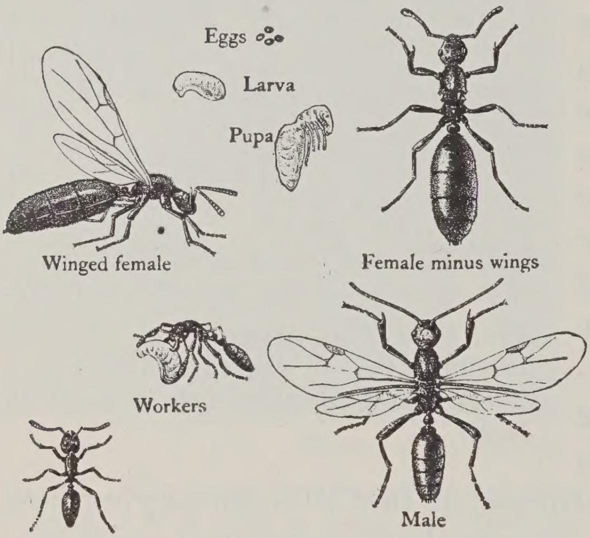
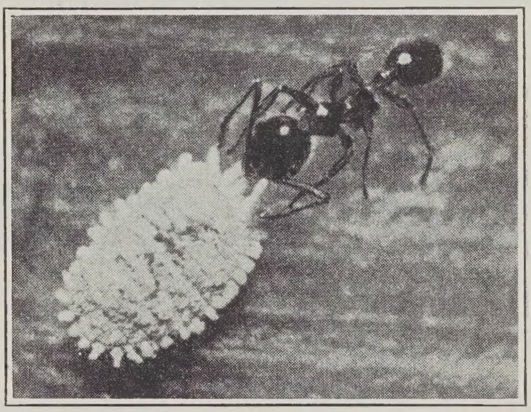


Fig. 69. The life history of the little black ant. How many kinds of adults are there? What does each do?

In the first place, the nest must be constructed. Underground, in the dark, passageways must be tunneled; chambers of many kinds must be dug out. When these are completed, constant repair is necessary. All this work is done by the *workers.* Every nest houses many workers, thousands of them, and one much larger ant known as the *queen,* a female who does nothing except lay eggs. Sometimes, it is true, there are several queens in one nest. And there are, too, a very small number of male ants that do no work. But the vast majority are workers and they are all kept busy, for they have many kinds of duties to perform. Besides their construction work they must go in search of food; sometimes they go far afield and drag home dead ants, other small insects, particles stolen from your pantries, as well as many other types of food. Much of this is stored in special chambers. Other workers devote themselves to the care of the young. Among the tasks they perform are feeding the larvae and moving the larvae or pupae from room to room so that they have proper conditions of temperature and moisture for their development.

Among some species of ants there are workers that biologists have called soldiers because they have very large biting jaws and apparently devote themselves to defending the rest of the community within the nest. Some warlike species even raid the nests of other ants. Their soldiers go out in large armies, marching in close formation. Among other less warlike species the workers make and tend gardens; here they raise a plant something like the mold you may have seen growing on damp bread or leather. Or they bring tiny aphids into the nest and feed them with great care. The aphids produce a sweet liquid which the ants relish. Thus the ant keeps aphids much as man keeps cows. "Barns" are built and the aphids are provided for during the cold winter months. The workers are said to stroke the aphid to make it give off its sugary liquid! Some species bring other kinds of ants into the nest to work as slaves. These slave-owners sometimes seem to become entirely dependent on their slaves.

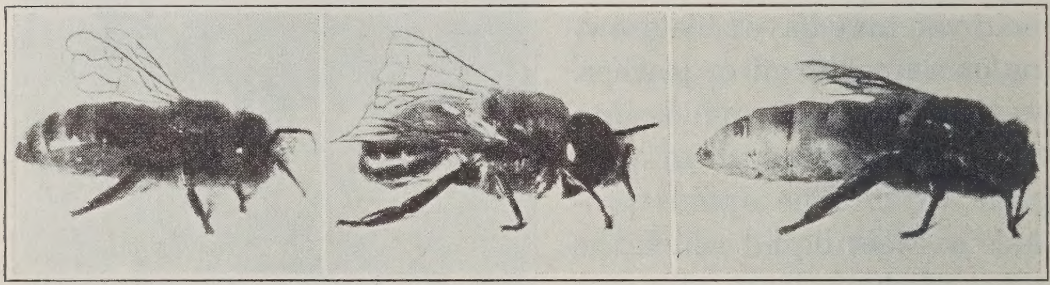


Courtesy American Can Co.

FIG. 70. An ant tending a mealy bug.

The life of the bee. The bumblebee, the giant among bees, leads a solitary life, laying its eggs in the ground. But most bees live in communities and build their nests in caves or hollow trees. As among ants, the queen is the central figure in the hive. She is fed and carefully guarded. She lays eggs, thousands of them, while the workers toil. They build the honeycomb. A liquid oozes out of their bodies; when it reaches the air it hardens and forms wax. They cut the wax into plates with their jaws and build the amazingly exact six-sided chambers. When these rooms are completed the queen deposits one egg in each. Other workers go out in search of food. Flitting from flower to flower they gather a sweet liquid which they store in a special honey stomach. When they return to the hive they give it up again to feed to the young. Or they change it into thick honey and store it in the hive for the winter. When a cell is filled with honey they cap it with wax. Often they gather pollen dust from flowers. This they prepare into special food and feed it to a few favored larvae only. In the meantime, they do much cleaning of the hive. The workers also meet the attacks of "robber" bees and other animals. For this, the bee uses the sting on the end of its abdomen.

After a time the eggs develop into adults. Although the life of a worker may be only several weeks or at most several months, the rapid rate of reproduction increases the number of bees in the hive enormously. Whether because of the crowding or for some other reason, in the early spring and summer large numbers of bees leave the hive in a mass to start another colony. This is called *swarming.*



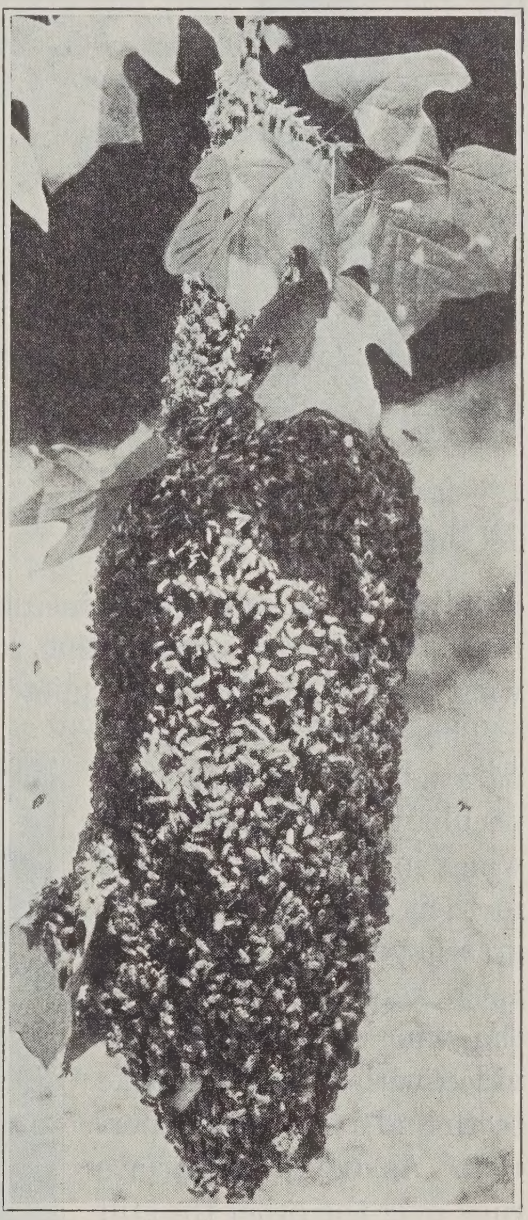
Courtesy A. I. Root

FIG. 71. From left to right these are worker, drone (male), and queen (female). How can you tell one from the other?

Domestication of bees. Centuries ago man discovered that the honey and wax produced by bees were useful to him. He has therefore taken to supplying bees with wooden frames in which they can construct their honey cells. In this way bee farmers obtain both honey and wax. Domestication has proved very profitable, but in all these years of domestication bees have never been tamed. This does not mean that keeping bees is dangerous. If you do not disturb them they will not harm you; however, a bee is easily frightened and then uses its sting.

Animals that eat wood. The community life of the so-called "white ant," properly named the *termite*, is just as interesting as that of bees or ants. Termites live mostly in the tropics but are spreading through the temperate zone where many of you have an opportunity to become better acquainted with them. They are not pleasant acquaintances for they destroy wood, thus sometimes even wrecking houses or other large wooden structures. They burrow and build in the wood. The young, as soon as they are able to use their jaws, go to work, building tunnels, cleaning house, tending the still younger ones, waiting on the queen, and feeding the soldiers. Keeping this standing army is quite a burden on the community. But by using child labor they can afford to keep a large armed force.

Working in the dark, well concealed in the timbers, their presence is not suspected until some day, when the underpinning has been weakened, the whole structure collapses. In warm climates or in cooler climates where buildings are constantly kept warm, termites are a real danger; the foundations and lower floors of buildings must be constructed of concrete to be safe. When this is not possible, soaking the timbers in creosote is helpful although not certain.



Courtesy U. S. Bureau of Entomology

FIG. 72. A swarm of bees. How does the bee keeper take advantage of swarming to start new hives?

You will learn later how it is that termites are able to eat and digest wood. That is an interesting story. But there are still other insects that chew wood, even though they do not use it as

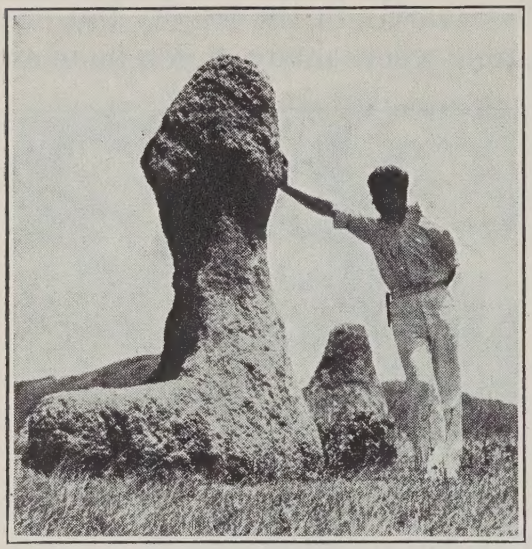


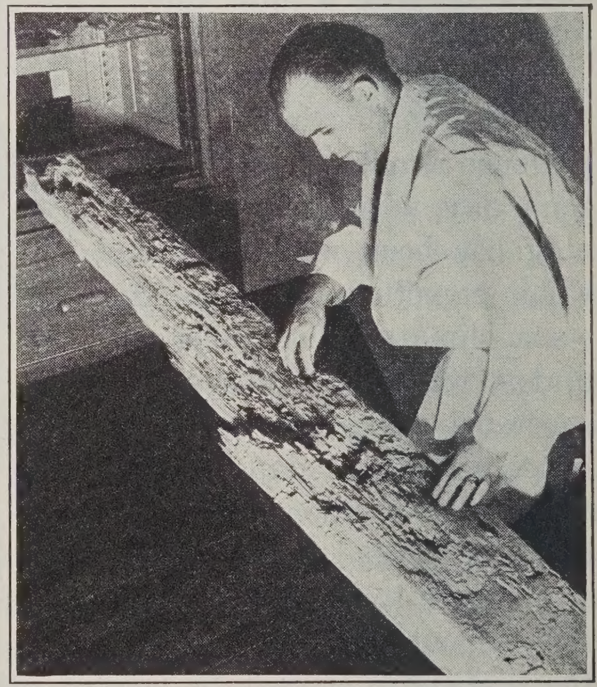
Photo by Hugh Davis

FIG. 73. A giant nest built by termites in Central America.

food. These are the wasps, those that build gray paper nests. They chew on little pieces of wood and work it over into paper.

How insects make a noise. In the summer time there is a steady chorus of the crickets chirping in the grass. As the days get hotter the male "seventeen-year-locusts" add their loud shrill song as persistent as a steam drill. When night comes on the katydids call from every tree, arguing endlessly "Katy-did, Katy-didn't." Not many of the insects are able to produce sounds but those that do are so noisy that many a city dweller has wondered what was meant by the "quiet" of the countryside.

The sound-producing apparatus of the cricket is peculiar. The front pair of wings in these insects (and in their near relatives, the grasshoppers and katydids) is thickened. The edges of the wing covers are provided with a set of filelike teeth and a scraperlike portion. As one rough surface rubs over the other the stiff wings are set into vibration. It is the vibration that is heard as a shrill chirping. In katydids and cicadas the apparatus is but slightly different. In all of them it is only the males that are so equipped.



Courtesy Science Service

FIG. 74. A beam of wood almost completely destroyed by termites. How might the wood have been protected?

Some insects, of course, make a noise by the extremely rapid beating of their wings. You know the malicious hum of the mosquito, the persistent buzz of the fly, and the droning of the bee.

The insects. So numerous and so varied are the insects that many books have been filled with accounts of their extraordinary structure and fascinating lives. This brief account has only scratched the surface. Since the study of insects is called *entomology* (en-toh-mol′o-jee), the biologists who study them are called *entomologists.* They can tell many exciting tales of the doings in the insect world.

Pupil Activities

1. Name ten animals with jointed legs. Are they arthropods? Why or why not? If you included no arthropods in your list, try to name five.

2. Why is the grasshopper a good example of an insect? If possible obtain the large lubber grasshopper for study. Find the three body regions. Compare them as to size. To which region are the legs and wings (appendages) attached? Study the rings or *segments* of the abdomen. How many are there? Of how many pieces is each segment composed? How may the overlapping of the segments be of use to the insect? With a hand lens look for a tiny opening on the side of each segment near the lower edge of the upper part. This is a breathing pore through which air enters the air tubes. Search for other breathing pores. Describe the position of the compound eyes. What might be the advantage of this position? With a hand lens look for simple eyes. Where are they? What is the advantage of having antennae that are segmented? Look under the wings; do you notice a smooth oval spot on the first segment of the abdomen? This is an eardrum. How does the first pair of wings differ from the second? What is the chief use of the second? Does your specimen differ from the picture in the text? How? Carefully spread out the lower wings. What do you notice? How many joints are there in each of the three legs? How do the legs differ from one another? Study the foot closely. Describe it.

3. How does the grasshopper jump? If you can obtain live grasshoppers watch them jump. How many times its own length does a grasshopper jump? In what position are the hind legs when the insect is about to jump? Compare with a man doing a broad jump. Explain. Does the grasshopper use its legs for anything but jumping?

4. Name as many insects as you can think of. Be sure that each one you name has the characteristics of an insect. As you read this chapter see whether you can discover the order to which each insect on your list belongs.

5. In the spring and fall of the year it would be easy to "swat" some flies and study them. How do they differ from the grasshopper?

6. How do you know that a small fly is not the young of a large fly?

7. Of what advantage to the butterfly and the moth may the scales on the wings be?

8. Examine the picture of the luna moth. How can you tell that this is a moth and not a butterfly?

9. Why is it that it is always moths and not butterflies that fly into your lamps at night?

10. How does the butterfly resemble and differ from a grasshopper? Study a specimen. Do you find head, thorax, and abdomen? What structure does the thorax of the grasshopper possess that is lacking in the butterfly? Follow the directions for study of the grasshopper. Feel the wing. If you have a microscope examine some of the powder which comes off on your finger.

11. Get the address of some large silk manufacturing concern and ask the class secretary to write for pictures or information on the raising of silkworms and the process of silk manufacture.

12. It would be interesting to learn how and where the silk industry started. A good encyclopedia would be of help.

13. If you have any plants in the house or garden examine the stems and leaves carefully for aphids or scale insects. Describe any that you find. Some kinds can be removed by holding the leaves and stems in soapy water.

14. Perhaps your class or biology club could buy an observation beehive, to keep at the window of your laboratory. You will learn a great deal about the life of bees.

15. Many books have been written on the social insects. Report.

16. You can buy silkworm eggs cheaply from many of the supply houses. If you can get fresh mulberry leaves you can raise silkworms in a box. Watch closely and keep notes on the changes that occur.

17. *Summary.* Since there are half a million species of insects it would be difficult to learn much about this large group in a short time. But you will have made a good beginning if you know exactly how you can recognize an insect; if you have become acquainted with grasshoppers and their relatives, moths and butterflies, flies, bugs, beetles, and the social insects. And remember that becoming acquainted includes recognizing them in all stages of their life histories.

Good Books to Read

Balfour-Browne, F., *Insects*. Holt.

Comstock, A. B., *Ways of the Six-Footed.* Slingerland-Comstock.

Ealand, C. A., *Insect Life.* Black (London).

Ewers, H. H., *Ant People.* Dodd Mead.

Fabre, J. H., *Book of Insects.* Dodd Mead.

Felt, E. P., *Popular Guide to the Study of Insects.* University of the State of N. Y.

Holland, W. J., *The Butterfly Book.* Doubleday. *The Moth Book.* Doubleday.

Huxley, J. S., *Ants.* Cape and Smith.

Lubbock, J., *Ants, Bees and Wasps.* Dutton.

Lutz, F. E., *Field Book of Insects.* Putnam. *How to Collect and Preserve Insects.* Am. Mus. Nat. Hist. Guide Leaflet No. 39.

Maeterlinck, M., *The Life of the Bee.* Dodd Mead.

Morgan, A. H., *Field Book of Pond and Stream.* Putnam.

Reinhard, E. G., *The Witchery of Wasps.* Century.

Teale, E. W., *Grassroot Jungles.* Dodd Mead.

Verrill, A. H., *Strange Insects and Their Stories.* Page.

Weed, C. M., *Insect Ways.* Appleton.

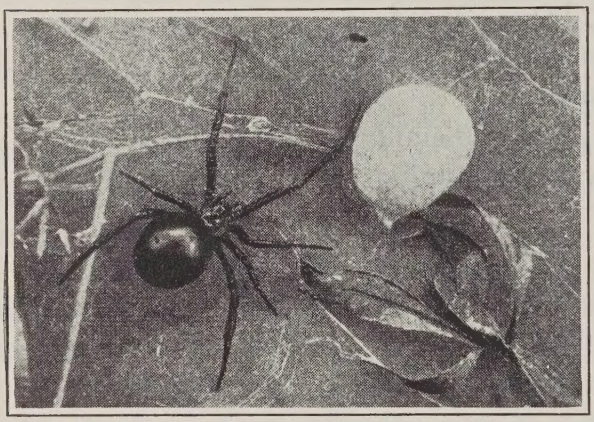
Wellhouse, W. H., *How Insects Live.* Macmillan.

Williams, S. H., *The Living World.* Macmillan.

CHAPTER VII

OTHER ARTHROPODS

Animals that resemble insects. You have read that the largest phylum of the animal kingdom is the phylum of arthropods, the animals with an outside skeleton and jointed legs. You have learned a good deal about arthropods by becoming acquainted with insects but the insects make up only one class of arthropods. There are many other arthropod species which, of course, resemble the insects but are sufficiently different from them to be put into separate classes. There are the spiders and scorpions (*class Arach'nida*); the centipedes and millipedes (*class Myria'poda*), and the lobsters, crabs, and their close relatives (*class Crusta'cea*).



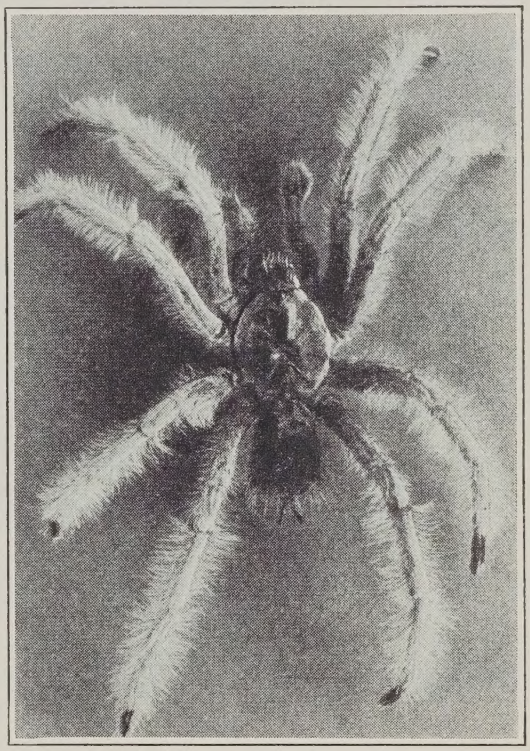
Courtesy Nature Magazine

FIG. 75. This black widow spider has lost one leg. Note its egg case near by. The black widow is dangerous.

How do spiders differ from insects? Does it astonish you to learn that spiders are not insects? You know that the spiders resemble the insects in having a firm outer covering and having legs with joints, but they are different in that they have four pairs of legs, not three. For another thing, spiders have the head and thorax joined together to form one region; the abdomen forms the other. Spiders are, therefore, made up of two body parts instead of the three found in the insects. Furthermore, they lack three kinds of structures found in insects: the wings, antennae, and compound eyes.

Spiders of which you may be afraid. Unfortunately, most persons are afraid of spiders no matter how harmless they are. This feeling, like the prejudice against snakes, is the result of ignorance and is unreasonable. The little house spider which spins cobwebs in the house does not bite; most garden spiders, too, even if they bite, can cause no more than a mild irritation.

The one spider which must be avoided because its bite may be serious is the black widow. It thrives best in the tropics, but within recent years has been found in many parts of this country. It is easy to identify for it has a small black body with a red spot shaped like an hourglass on the under side of the abdomen. This spot has given it another name, the hourglass spider. The tarantula can give an ugly bite but, in spite of its bad reputation, does not often cause death in a human being. It hunts at night, and in the daytime hides under logs and stones. Tarantulas are so large that they can catch and eat small birds but, for the most part, they depend on insects for food. Though natives of the tropics, tarantulas are sometimes brought north by steamers carrying bananas or other fruit.



Courtesy U. S. Bur. Entomology

FIG. 76. With legs outstretched the tarantula may measure more than seven inches across.

The spider's web. If you have walked in the woods on a path not frequently traveled you have felt on your face and hands the touch of a spider's thread. This is usually nothing more than a line thrown out by some spider as it moves about or a thread that anchors the spider's web. Some spiders, like the house spider, spin a tangled mass of threads in some quiet corner. This is a cobweb. True webs are complicated structures woven according to a definite pattern. You may have seen them gleaming in the grass early in the morning when the dew outlines each thread. They may be flat like a wheel with spokes, or funnel-shaped, or of some other form, for each species has its own characteristic web. But the threads are always produced in the same way. A special liquid is forced out of the abdomen. When it reaches the air it hardens into a silk thread, as in the case of the threads spun by the silkworm.

Some spiders use their webs as their homes. But many use the web merely as a means of catching prey and live near by in specially constructed nests. In these cases, the web consists of two kinds of threads. The main lines, some of which hold the web to its supports, are dry and firm. The other threads are sticky and elastic. Once one of these threads is accidentally touched by an insect, it gives like the net which catches the trapeze swinger in the circus. The insect bounces up against some other sticky threads. In an instant it is entangled. The more it struggles, the more hopelessly does it tend to become caught. Nor does it take long before the spider appears on the scene. For, even when completely out of sight, it is holding on to some of the main lines. Thus it detects every jar of the net and it can pounce upon its victim in a flash.

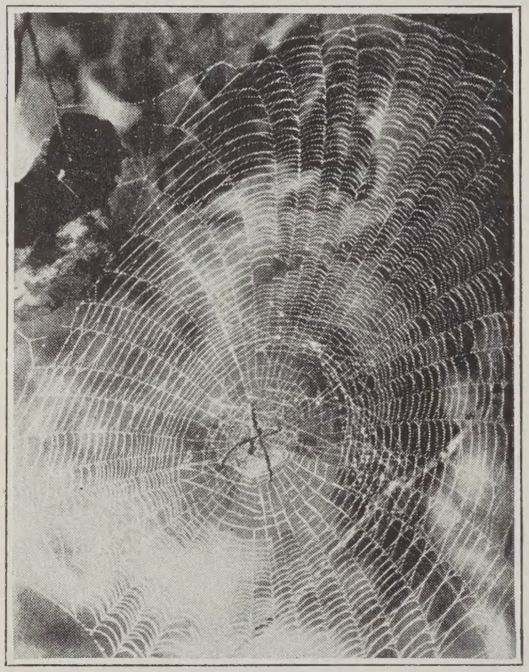


Photo by Hugh Davis

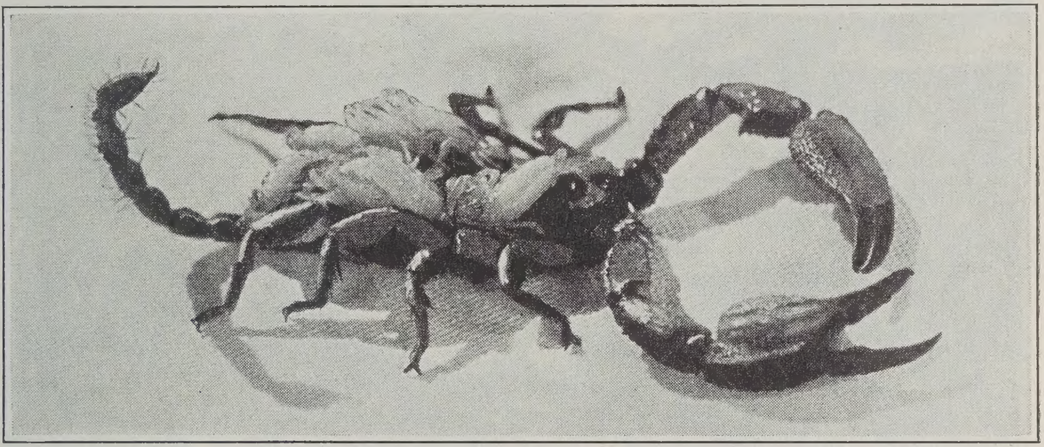
FIG. 77. The garden spider spins an orb web of this kind. It rests motionless in the center.

There are certain spiders that never spin a web. The trapdoor spider digs a hole in the ground and then covers it with a door opening outward on a hinge. This door is made largely of silken threads. Threads of silk are used, too, to line the nest, making a cozy home in which the spider hides except while it is out hunting for prey. Other spiders live in the open, spinning rarely, if at all.

Arachnids that are not spiders. There are some arachnids that resemble spiders so little that you would probably not see the resemblance. The scorpion is one. You may have heard of it as an animal to be dreaded. As a matter of fact, the scorpions of this country cannot do much harm. But in the tropics, where they may be as much as eight inches long, they may be dangerous to man. When disturbed, the scorpion looks like a fighter. And like many another animal which is armed, it is quick to defend itself.

There are tiny arachnids, perhaps a little more like spiders, known as mites and ticks. Many of them live on, or just under, the skin of various mammals, including man. They are always unpleasant; some of them, like the chigger, cause fierce itchings. In some cases they are carriers of dangerous disease germs.

Another arachnid which looks much like a spider is the harvestman. You may know it as daddy longlegs, from its unusually long and spindling legs. It has no silk glands and does not build a nest or hiding place as most spiders do. The legs drop from the body so easily that the gentlest handling is likely to leave the harvestman looking more like an insect than like an arachnid.



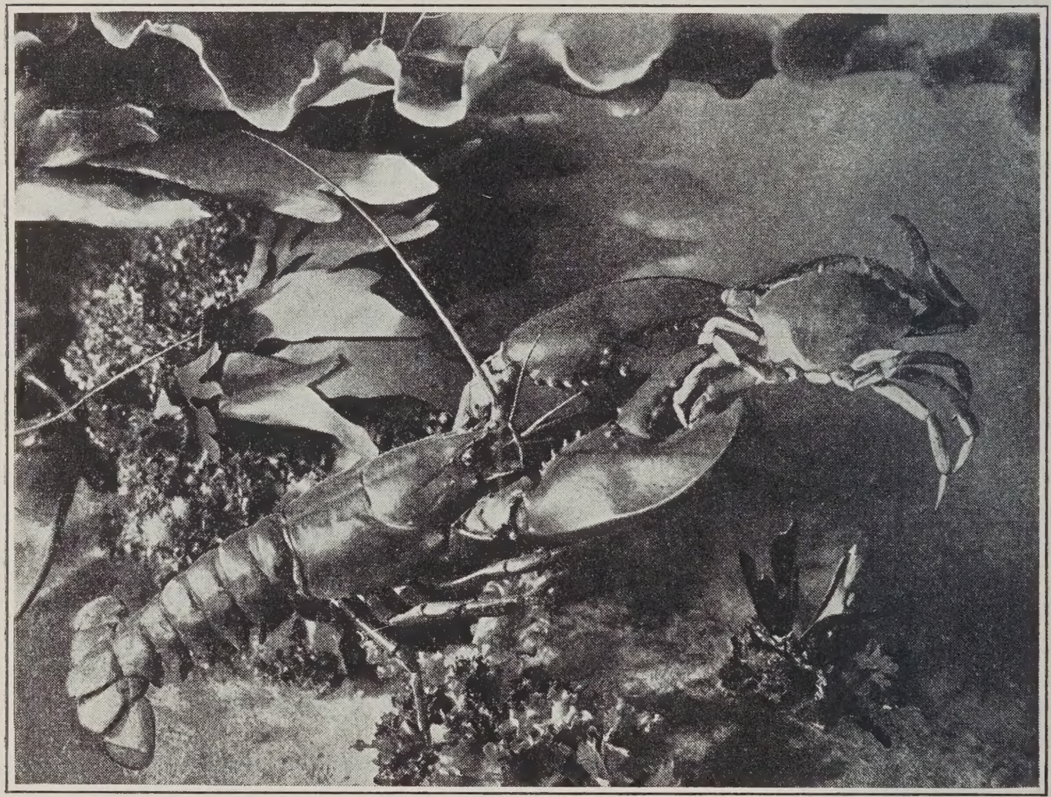
Courtesy American Museum of Natural History

FIG. 78. This scorpion shows how the young are carried on the back. The sting at the end of the abdomen can be waved over the head.

The thousand-legged arthropods. (*Order Myriapoda.*) Their bodies are made up of a series of rings; that is why many persons think that they are worms. But there are legs attached to each ring. Some forms have a pair of legs on each ring; these are the centipedes ("hundred-footed"). Others have two pairs of rather short legs to a ring. These are the millipedes ("thousand-footed"). While the centipedes can run with a speed which seems to be in direct proportion to the number of legs, the millipedes crawl as slowly as a worm. When disturbed they may roll themselves up into a ball.

The most familiar centipede is the little house centipede. You may find it in the cellar, if it is damp, or in the bathroom. It is a useful animal since it eats cockroaches and other insects. The centipedes of the tropics are big fellows; they may be a foot long.

The arthropods of the sea. (*Order Crustacea.*) You have become briefly acquainted with many kinds of arthropods: the insects, the arachnids of various kinds, and the many-legged arthropods. With few exceptions, all of these live on land or in fresh water.



Courtesy American Museum of Natural History

Fig. 79. Lobster catching a crab. Why are they called Crustacea?

There is a fourth great arthropod group, the Crustacea (krus-tay′-she-a), which includes many forms that inhabit the sea. Not that all Crustacea do, however; some live on land and some in fresh water.

It is difficult to state by what characteristics you can recognize Crustacea. About all that can be said here is that if an animal seems to be an arthropod and does not exactly fit into the insect, arachnid, or centipede groups, it is probably a crustacean. You have already read of some: the lobsters and crabs. There are also crayfish, water fleas, barnacles, shrimps, and hundreds of others.

Some queer Crustacea. Perhaps all Crustacea deserve to be called queer. The lobster is just an ordinary kind of crustacean, as these animals go; but it has eyes that are on the ends of stalks, huge pincers or claws, and glues its eggs to its legs. In spite of the saying "as red as a lobster," it is not red at all; not until it is boiled. Then its dark greenish shell turns a brilliant red. Fortunately, lobsters are not very quick with their claws for they have a tremendously powerful grip and can inflict dangerous wounds.

The crab has the same strange eyes, but its body is different; it is wider than it is long, and it seems to have lost its abdomen entirely. The queerest thing about it is its walk. It walks sideways, but it manages pretty well. And in the water it is a good swimmer. Along the coast you can often buy soft-shelled crabs. This is not an unusual species but a common crab that is without a shell for the time being. All the Crustacea with hard coverings must shed their coverings once in so often to give them a chance to grow. Young crabs and lobsters which grow to a good size spend a good part of their time splitting their skeletons down the back and crawling out of them.

But, for strangeness the barnacles take the prize. It was a long time before they were recognized as relatives of lobsters and crabs. A famous English biologist, T. H. Huxley, has given this striking description: "A barnacle may be said to be a crustacean fixed by its head and kicking the food into its mouth with its legs."

You may have read in sea stories of the ship barnacle or goose barnacle. Its little body with its kicking legs is equipped with a long stalk, at the end of which is a cement gland. This enables it to fasten itself to objects under water. For some reason it chooses moving objects like floating logs or ships. It used to be a great nuisance. When ships were kept pretty constantly in the water thousands upon thousands of these animals would gather on the hull. Seamen then said that the "bottom was foul" for the ship could not slip through the water easily.

The rock barnacle may also attach itself to boats but most of them live on rocks in the area between tides. Stay away from them. Whether the shells are open or shut their sharp edges will slash your flesh if you brush up against them. When the tide is out the barnacles look like rough, white rock. They are resting then, between meals. But watch them when the tide is in. The shell valves open and the legs begin their constant waving. Although you will not be able to see the tiny particles of food, you may be sure that the animal is kicking food into its mouth.

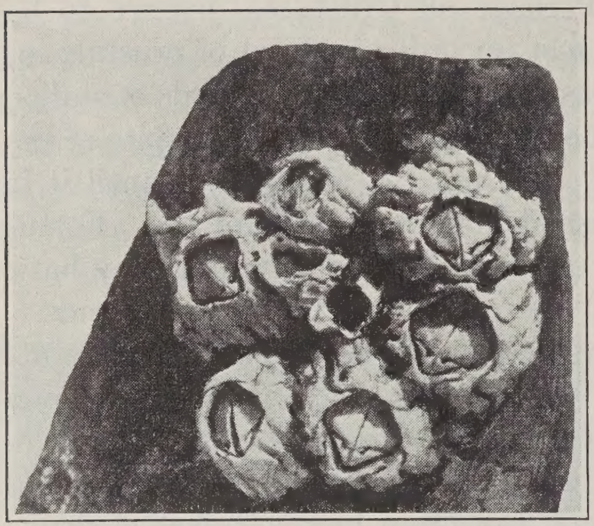


Photo by Percy Morris

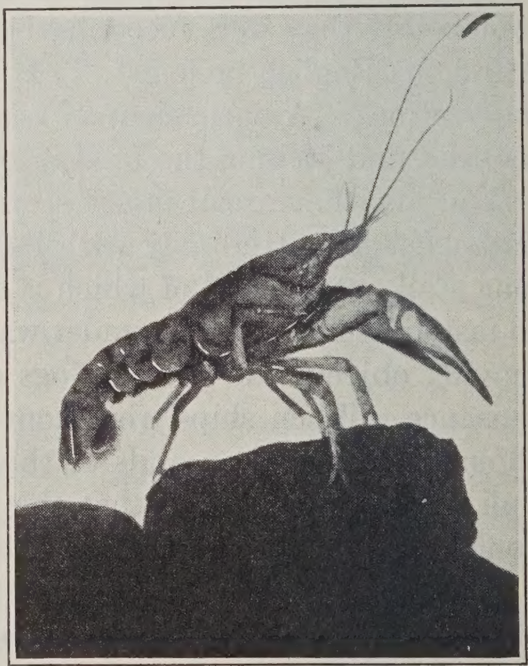
FIG. 80. Rock barnacles. Almost 3000 of them have been counted on one square foot of rock.

There are many land-living crustaceans. One is a little grayish creature known as the wood louse or pill bug, that may be found under bark and among loose stones. It breathes through its legs!

Another queer crustacean is called "Cyclops" after the giant of Greek mythology. You may remember that the Cyclops had only one eye and it was in the center of his forehead. Cyclops, the animal, has a single eye-spot in the center of its head. It is a tiny animal, barely visible without a lens. It can be seen in fresh water, swimming by a series of jumps.

Crustacean homes. Only a few of the many species of this group may be said to have homes. The crayfish is one. It lives in fresh water, usually in a stream which has muddy banks. Here it digs a cave or tunnel in which it remains during the day, coming out at night to search for food.

The fiddler crab lives in a burrow, too. Its home is usually in the mud flats near



Courtesy N. Y. Zoological Soc.

FIG. 81. The crayfish walks over rocks in a stream. Which animal does it resemble closely?

the sea. As you appear, it scuttles off sideways to its hole, backs in, and disappears. But in a moment curiosity or impatience gets the better of it. You see a big claw reappearing at the entrance and cautiously the crab crawls out, waving its big claw as though it were a fiddler's bow. It looks silly to us but no doubt threatening to some smaller animal.

The most interesting home of all, though, belongs to the hermit crab, which makes use of the empty shell of a sea snail. When the hermit crab finds a shell of a suitable size it backs in and thereafter carries the shell with it. Curiously enough, the body of the crab is soft and twisted so that it can fit into the spiral sea shell. After it has adopted its house all that can be seen of the crab are the big claws and the head. After the crab has grown so much that its shell fits too tightly, it moves into a new house. If it finds nothing suitable "for rent" it may dispossess another crab and move in.

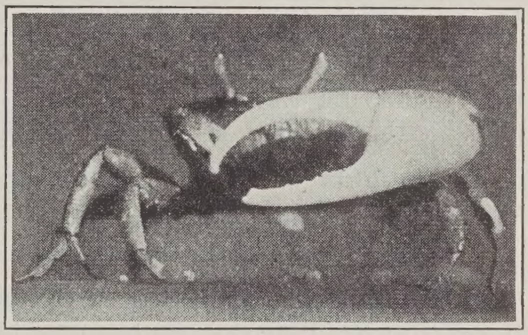


Photo by Mary C. Dickerson

FIG. 82. The fiddler crab tiptoes over the sand. Do you see its eyes raised on stalks?

There are many other species of arthropods in the groups mentioned above but they are too numerous to be described here. It takes a long time to become well acquainted with so varied a phylum.

Pupil Activities

1. Could you draw a diagram of the top view of an insect and another of a spider to show the important differences between the two groups of animals?

2. If you can get a preserved black widow spider it would be helpful for you to make a large chart showing both the upper and the lower sides of this poisonous spider so that all the students may become well acquainted with it.

3. Spiders can be raised indoors if you supply them with enough small insects. Fruit flies may be raised for the purpose.

4. Why may a daddy longlegs that has been handled look more like an insect than like an arachnid?

5. Shrimp and lobsters are easy to obtain in the market; crayfish are common in fresh water streams. Study and describe the body regions and the appendages of one of these Crustacea. Study the antennae and the eyes. In each case compare with the grasshopper. What differences can you find among the many pairs of legs of the crustacean? How might it use these various kinds of legs? What is the advantage of the segmented antennae and jointed legs?

If you have live animals, place them in deep water in a large tank and then in a shallow tray to watch the methods of locomotion. Hold the crayfish in your hand; does it exert much strength in trying to escape? Do you think the animal is well protected by its color? Gently touch the eyes with a pencil. What does the crayfish do? What is the advantage of having the eyes on stalks? Have you made any other observations of your own? If so, discuss them with the class.

6. Daphnia is a tiny crustacean that is easy to obtain and raise. Write to any large biological supply house and ask for directions.

7. The forms mentioned in this chapter and other arthropods affect man in many ways. Can you prepare lists of those that are useful and those that are harmful, telling how in each case?

8. *Summary.* You have become acquainted with three groups of arthropods besides the insects. Name a few forms in each group. Tell how they live.

Good Books to Read

Comstock, J. H., *The Spider Book.* Doubleday.
Duncan, F. M. and L. T., *Spiders and Scorpions.* Oxford Univ. Press.
Fabre, J. H., *Life of the Spider.* Dodd Mead.
Fuller, R. T., *Along the Brook.* John Day.
Morgan, A. H., *Field Book of Pond and Stream.* Putnam.
Porter, W. P. and Hansen, E. A., *The Pond Book.* American Book.
School Nature League, *Crustaceans — Armored Animals of the Seashore. Interesting Spiders.* The League, New York City.
Williams, S. H., *The Living World.* Macmillan.

CHAPTER VIII

OTHER INVERTEBRATES

1. Soft-Bodied Animals. (*Phylum Mollusca*)

What are molluscs? Oysters and clams belong to the group of molluscs. But the group also includes animals which look different from them. The snail which crawls about with a shell on its back and the octopus with its long waving legs are also molluscs, as well as other animals less well known to you. They all have soft bodies, often protected by a shell of lime. The biologist puts them in the same group because when he dissects them he finds their organs to be remarkably alike. All of them have a muscular organ known as the "foot" which probably would not suggest a foot to you at all. The biologist distinguishes three distinct classes: those which have a "foot" for seizing prey, like the octopus; those that have a "foot" for creeping, like the snail; and those that have a wedge-shaped "foot" for plowing through sand or mud, like the clam.

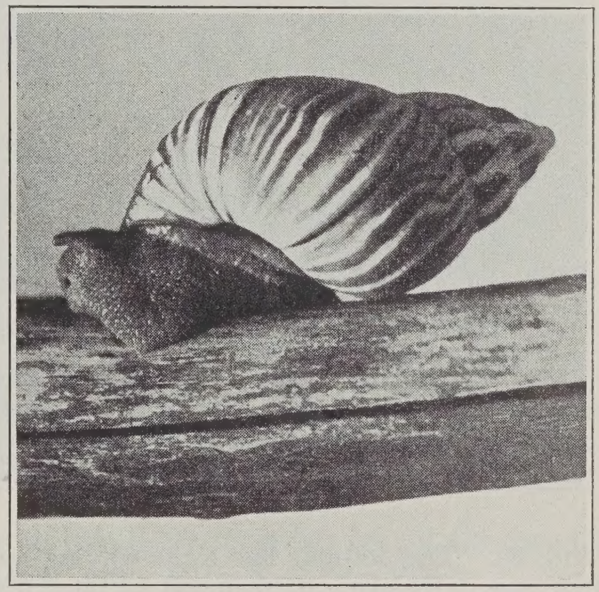
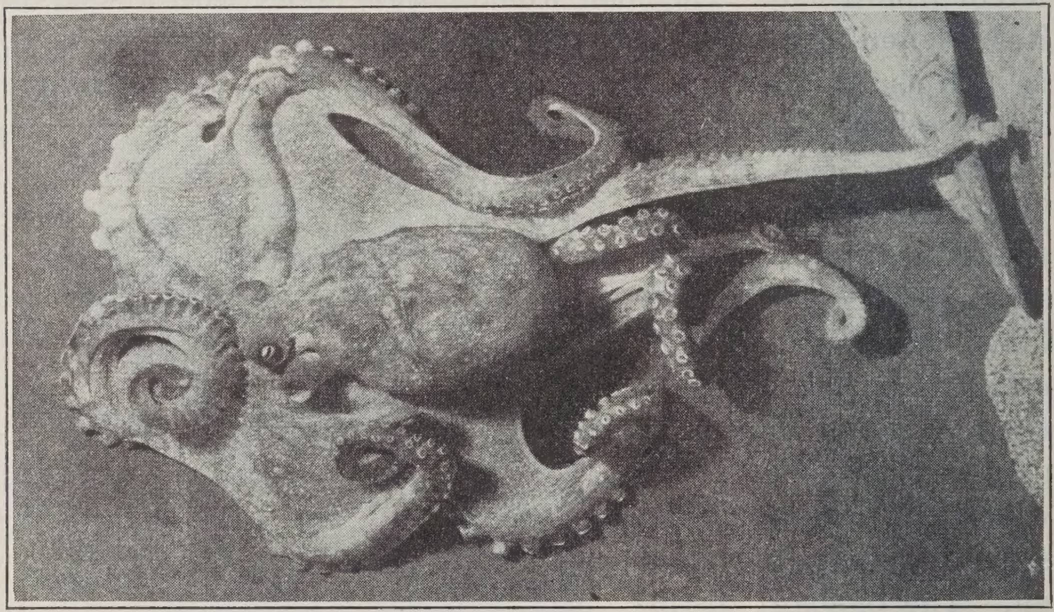


Photo by Hugh Davis

FIG. 83. This zebra snail is walking on its foot.

Molluscs with a hatchet (wedge-shaped) foot. These are the oysters, clams, and mussels. They have a double shell; that is, a shell consisting of two valves. That is why they are called bivalves. Often the shell is left open and the hatchet foot, a thick piece of muscle, may stick out. But the two shells can be drawn together and closed so tightly by muscular action that it takes great strength and a particular knack to pry them apart with a strong knife. In the oyster, which spends its life attached to rocks or other oyster shells, the foot is so small that it can hardly be said to have one. But the clam uses the foot for locomotion, plowing along through the sand.

Molluscs that creep on the foot. Snails have a much larger foot, especially conspicuous in the land-living forms. They have a well developed head, too, with a real mouth, and eyes carried on long stalks. When danger threatens, both head and foot are drawn into the spiral shell and the tough, slimy foot seals the mouth of the shell so well that it is difficult to extract the animal.



Courtesy New York Aquarium

FIG. 84. The octopus has eight waving tentacles (or feet) which bear sucking cups. By using its feet and its beak it tears its prey to pieces.

Molluscs that seize their prey with their feet. These molluscs, the octopus (also called the devilfish) and the squid, look least like clams and oysters. They are equipped with many feet in the region of the mouth called *tentacles* (ten′ta-kels). The tentacles are dotted with sucking cups by means of which they can get a strong grip on some other animal. While a few of these molluscs have large shells, many of them have no shells at all, and some have only small shells completely hidden underneath the skin. This is true of the cuttlefish, a variety of squid. You may have seen its white shell hanging in a canary's cage so that the bird might sharpen its bill. The squid and octopus have a curious habit of swimming backward. But the octopus can also use its tentacles for walking over the ocean floor, in which case it moves forward. Both, too, can squirt out an inklike substance which serves to conceal them from their enemies.

Although there are hair-raising stories about the activities of the octopus (devilfish) and the giant squid, they actually do little harm. It is true that they look terrifying, for the giant octopus of the Pacific Ocean may be twenty-eight feet in diameter, and the giant squid has been known to be fifty feet long (including the tentacles); but one would have to go far out of his way to fall into their clutches.

Molluscs useful to man. A surprisingly varied lot of molluscs are eaten by man. A great many species of bivalves grace his table, the oyster and the clam being the most common. But they are far from being the only bivalves man eats; scallops and mussels are favorites the world over. Although you have probably never thought of trying them, snails are considered a delicacy in many countries. And the octopus and squid are eaten regularly and with relish by those who can get them fresh and who know how to prepare them.

Custom and habit prevent many of you from tasting snails or squid. But if you do not consider squid good eating, fish do. And so squid are valuable on the northeast coast because they are used as bait by the fishermen who follow the cod off the banks of Newfoundland.

Oysters seem to have been enjoyed by man for many thousands of years. Huge piles of oyster shells have been found in ancient garbage heaps that have been dug up in various parts of the world. Oysters are valuable also as the source of mother-of-pearl, from which buttons are made. Occasionally some fortunate person finds a pearl in an oyster, but precious pearls come from special tropical species.

Pests among the molluscs. One of the worst of the comparatively few molluscan pests is the "shipworm." It is a sea-living bivalve with a long body, shaped much like a worm, with the two valves of the shell at one end. It bores into timber which is under water, riddling it with tunnels until the wood collapses. Now that ships are made of steel, the shipworm can do no damage to them. But wharves are still made of wood and sometimes the "worm" does enormous damage there. During the years 1917 to 1921 there were so many shipworms in San Francisco harbor that they destroyed $25,000,000 worth of wharves.

Another harmful member of the phylum is one that seems to relish raw oysters as much as man. It is a tiny snail well named the oyster drill. This mollusc obtains its food by filing a hole through the shell of an oyster and sucking out the contents. All snails have "files" in their mouths but this one has a particularly strong one which enables it to work through the hard shell of the oyster.

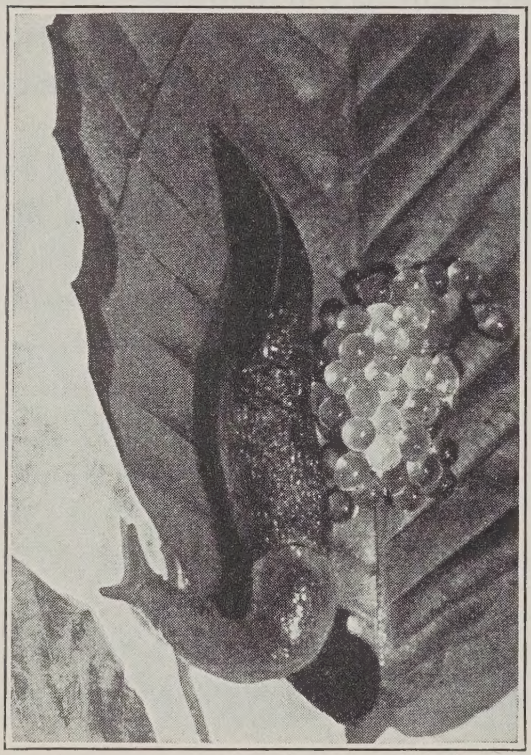


Photo by Mary C. Dickerson

Fig. 85. Although the slug is a mollusc belonging to the same group as the snail, it has no shell. This one has laid its eggs on a leaf.

Land snails and slugs, in general, are pests because they eat the fresh green leaves of garden vegetables. Luckily, they cannot eat a great deal and are usually present in small numbers.

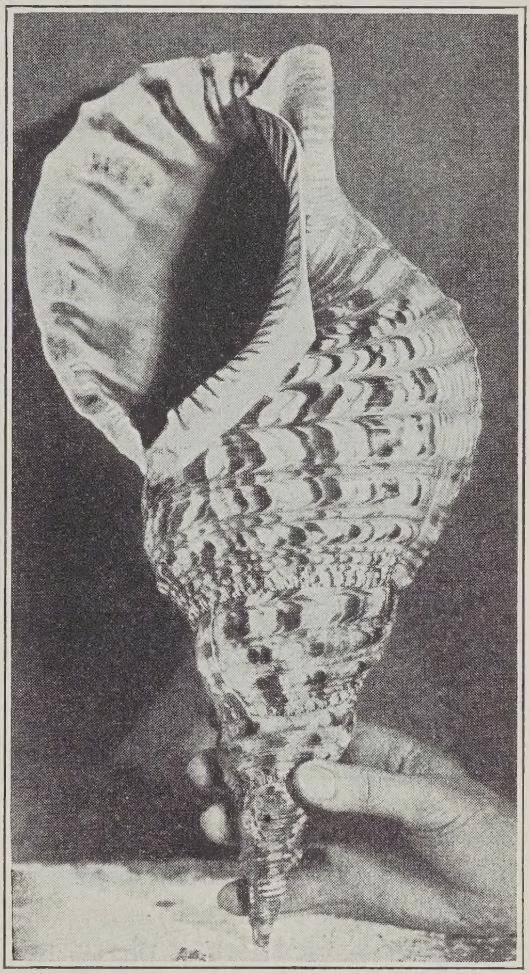
Shell collecting. Most interesting, because of the large variety in shape, in texture, and in color, are the shells with a single valve. A few, like the brilliantly colored abalone and the delicate limpet are plain and untwisted; but most of them have spiral points of varying heights.

Most are what are called right-handed shells; that is, if you use the tip of a finger to trace the spiral from its very tip down to the broad opening, your hand will be moving like the hands of a clock. There are a few shells whose spiral goes the opposite way; they are called left-handed. Beautiful colors are not uncommon in these shells, particularly in those which come from salt water.

The largest of the shells found on our coasts is the queen conch. It is common off the shore of Florida and the West Indies. This shell may be a foot long and weigh five pounds. The spire is short and the opening has large lips tinted rose and pink. You may have seen one on a mantelpiece, because it is a favorite ornament.

Among the bivalved shells, the heart-shaped spiny cockle and the scallop deserve special mention for their beautiful designs. The razor shell is an interesting variation of the clam. It is delicate, pure white and looks like an imitation of an old-fashioned razor, or, rather, of two razors which enclose the long, narrow body of the mollusc.

Many people collect shells as others collect stamps. This hobby, like insect collecting, has one advantage that stamp collecting cannot have; it takes one out into the open, to beaches and rocky coasts, along the banks of streams, and into the woods.



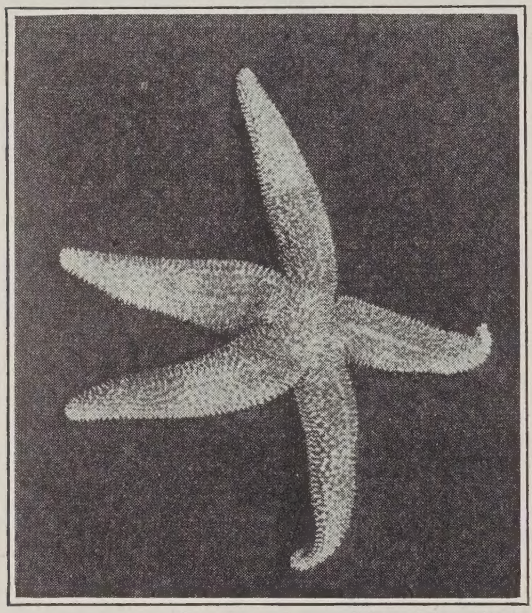
Courtesy Amer. Mus. Nat. Hist.

FIG. 86. The triton's trumpet may grow to a length of 18 inches. Is this a right-handed or left-handed shell?

2. The Five-Rayed Animals. (*Phylum Echinoderma*)

The starfish. The starfish has nothing in common with a fish except that it dwells in the water. But it is a "star," a living flexible star of beautiful brown or red or purple color. Since the five arms are of nearly the same size, the starfish cannot be said to have a beginning or an end. In fact, it indicates this by walking in any direction. During the day it rests, clinging so firmly to a rock that the beating of the wildest ocean waves cannot loosen it from its hold. But at night it glides or crawls along in search of food. It does not often use the "arms" for locomotion. Instead it makes use of hundreds of tiny tube feet which dot its lower surface. These are pushed out and pressed against the ocean floor until they cling by suction. There is a complicated water system running through the whole body; these small tube feet are branches of it. When water is forced into these branches the suction is released. Thus by moving the many tube feet in succession the starfish moves along slowly and smoothly.

These tube feet help in breathing, too, and in food getting. Oysters are a favorite food and the starfish does not wait to have them served on the half shell but undertakes to open the oyster for itself. The starfish folds itself over the oyster shell, attaches its tube feet and exerts a steady sidewise pull. There it stays until the oyster is forced to give in. As soon as the two valves of the shell have separated, the starfish turns its stomach inside out, thrusts it into the shell, and digests the living animal in its shell.



Courtesy Amer. Mus. Nat. Hist.

FIG. 87. This shows the horny, rough upper surface of a common starfish.

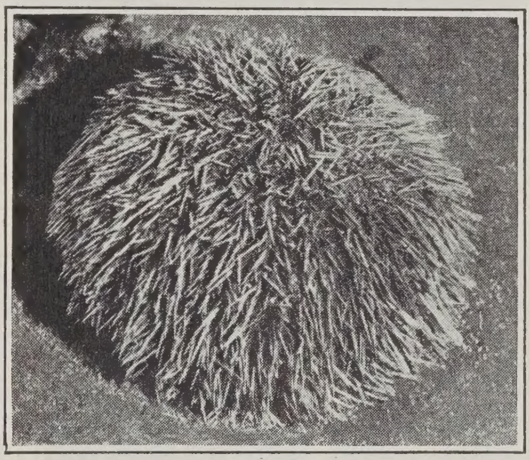
Starfish are common close to shore, where they do much damage by feeding on molluscs. Oystermen formerly tried to destroy starfish by tearing them in half and throwing the pieces back into the sea. Unfortunately, this made the situation worse, for both halves will grow back the lost parts, making two animals where there had been but one before. Nowadays the starfish are tossed up on the beach, where they die.

Relatives of the starfish. Unless you live near the coast you have probably never seen a living starfish or any of its relatives, as they inhabit the salt water. Many of them have interesting names, for the name often describes the animal, and these animals are all unusual. The nearest relatives of the starfish are animals called basket stars and brittle stars. The brittle star got its name from a curious habit of breaking off its own arms when they were injured. As in the starfish, the arms grow back.

Other relatives are the sea urchins and sand dollars. Like the starfish, they have their mouths on the lower side. They take in sand, in which they find small animals and plants to serve as food. The sand dollar has a shell that looks like a large dollar somewhat thickened in the middle. The sea urchin is so covered with movable spines that it looks like a walking pincushion. Along the French and Italian seacoast it is gathered as food. You will find them in some of the markets of this country, too. Its large masses of eggs are considered a great delicacy. But scientists have a more important use for them. For many years the eggs have been used in laboratory experiments by biologists interested in the growth of an animal from its egg.

A third class contains the sea cucumbers. In shape they certainly look like cucumbers but if you ever tried to eat them raw you would find them much too tough and leathery. Dried and made into soup they satisfy many peoples in the eastern countries.

The sea lilies are in still another class of this phylum. If you have ever seen pictures of them you probably thought they were plants. Even in life they look like plants, gracefully waving many branches from the top of a long stalk. They grow attached to the muddy or sandy bottoms of tropical seas. At the free end of the stalk are five much-branched arms. These capture food and push it into the mouth which lies at the base of the arms.



Courtesy Amer. Mus. Nat. Hist.

FIG. 88. The sea urchin has a beautifully marked shell beneath these spines.

All these animals show the five-rayed structure of the starfish. All have another thing in common: a tough, spiny skin. That is what the name echinoderm (e-kyn′o-derm) means. Dissecting these animals and discovering the resemblances for oneself is an exciting game.

3. Worms of Various Kinds

The earthworm and its relatives. (*Phylum Annelida.*) Everyone knows what an earthworm is; it is a common inhabitant of the soil almost everywhere. You see dozens of them after a rain has forced them up out of their burrows. At night, too, especially when it is damp, you may see them above ground if you search for them. But ordinarily they stay underground, for their skins are thin and moist and the sun quickly dries them out and kills them. They burrow through the earth in search of decaying plant material which serves them as food. But if the soil is tightly packed they must literally eat their way through the earth. They swallow all the soil particles that lie in the way. Within the earthworm's digestive canal the food materials are separated out and used; the undigested soil is left behind in little ropes which hold together until they are dry. You may have seen them on the ground; they are called *castings*.

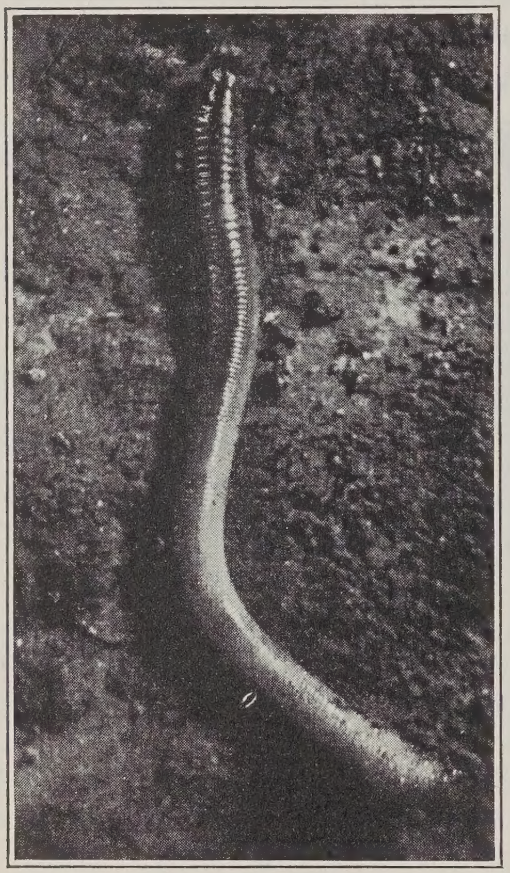


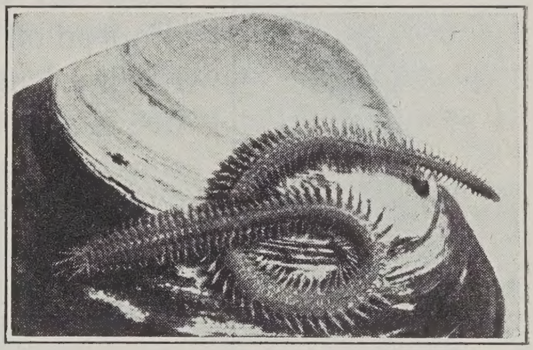
Photo by H. Schneider & J. Schwartz

FIG. 89. An earthworm burrowing in the soil. How does it differ from the clam worm?

The great biologist, Charles Darwin, and his sons studied the activities of the earthworm with great care. They discovered that the animal regularly brought its castings to the surface and that, therefore, earthworms were constantly plowing and cultivating the soil on a small scale. Darwin calculated that, in regions where earthworms are plentiful, they bring up eighteen tons of castings on an acre of ground in one year. For this reason, the earthworm, unimportant as it may appear, is an animal of great value to man.

If you have ever looked at an earthworm you must have noticed that it seems to be made up of a number of rings placed one after the other. The biologist calls each ring a segment; thus the earthworm is a segmented animal. All the worms in this phylum are segmented.

But not all the members of the phylum of segmented worms live in the soil; some live in the water. There is one fresh water form that is rather common: the leech. It has suckers at both ends of the body which enable it to stick tightly to the animal from which it sucks blood; that is the origin of the expression, "sticks like a leech." It has teeth with which it breaks through the skin and a substance in the saliva which prevents the clotting of blood so that it can suck until it is full.



Courtesy Nature Magazine

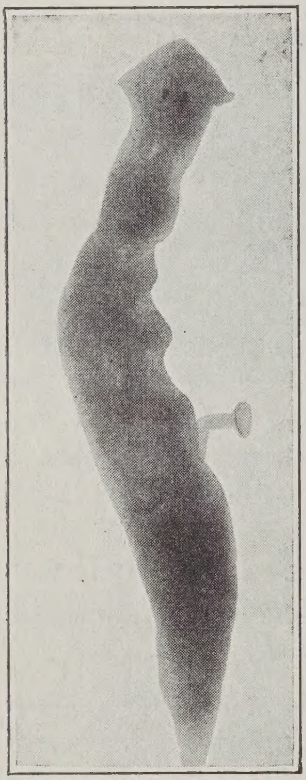
FIG. 90. The clam worm lives in the ocean near the shore. It may be a foot or more in length.

Its meal is a huge one, too. Leeches have sacs which can hold blood for long periods of time; the animal swells up until it looks as if it would burst, then goes off to rest while it digests the blood slowly. It can go without food for many months. Formerly it was common practice to treat disease by allowing leeches to suck the patient's blood.

Worms without segments — the roundworms. (*Phylum Nemathelminthes.*) The roundworms have no segments. Most of them are tiny; too small to be noticed unless one is searching for them, and often too small to be seen with the naked eye. They are present in large numbers almost everywhere, particularly in the soil. Some of them, like the hookworm, have taken to living in the bodies of other animals, including man. These are among our worst enemies. You will read about them in later chapters.

More worms without segments — the flatworms. (*Phylum Platyhelminthes.*) One very common flatworm, Planaria (plan-ay'ree-a), lives in sluggish streams, hidden under stones. You have probably never found one, for it is less than $\frac{1}{4}$ inch long, flat, and of a grayish color so that it is hard to see. But once you have seen it you will always know it by its shape. Its mouth is not where you would expect it to be, at the front end; it is near the middle of the body, underneath. It lies at the end of a tube which is kept inside the body. But when Planaria eats it extends the tube so that the mouth can come in contact with the food.

There are other flatworms that are of great importance to man because they attack him or his domesticated animals. The liver-fluke lives in the liver of the sheep, or occasionally in the liver of some other mammal. It does great damage to the flock. Another species is the tapeworm. It is flat, like a ribbon, but it is a ribbon made up of separate pieces which can be dropped off one by one. The tapeworm may reach a length of twenty feet. Some species live in man's intestine, hooked to the wall by the curved spikes and suckers on their heads. They live on the food which man has digested.



Amer. Mus. Nat. Hist.

FIG. 91. Planaria has two eyespots on the head. Do you see the eating tube?

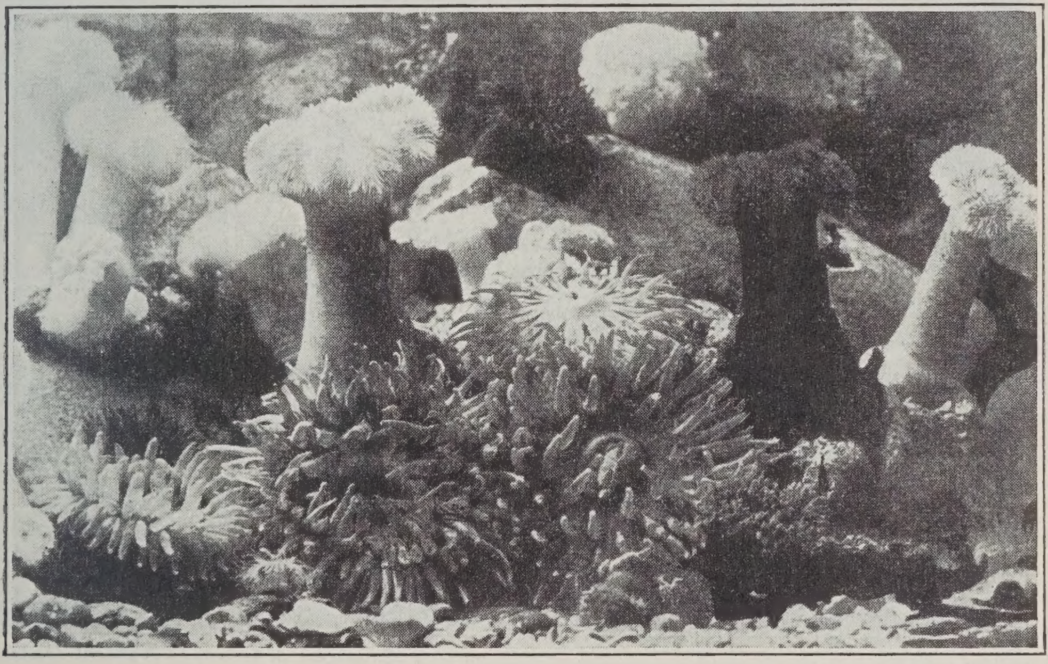
4. The Most Beautiful Animals of the Sea. (*Phylum Coelenterata*)

Sea anemones. If you see a crown of gaily waving tentacles above a delicately tinted body that is fastened to the sea bottom you are looking at a sea anemone (a-nem′o-nee), the "flower" of the ocean. Many are brown in color, some forms are pink or rose-colored, others are orange or bluish green. The sea anemone's body is little more than a sac for digesting food. The mouth is a slit-like opening in the upper end of the sac; the tentacles that surround it grasp the food which the water may wash within reach. They can shoot out long stinging hairs which paralyze or kill their prey. Once the food is caught the tentacles push it into the mouth.

When the tide goes out leaving the little anemone in its rocky pool, it pulls in the tentacles, which are now useless to it, and contracts its body until it is nothing but a small solid mound. This is the best defense it has against its enemies, which are not many. Although most anemones are just a few inches wide, there is one species which measures a foot across.

Animals that make rock. Another class includes the coral animals. Although they are closely related to the sea anemones they differ in several ways: they are usually much smaller; they rarely live singly, but grow in large groups or *colonies;* and, most important of all, they build shells of lime outside their bodies. These are not detachable shells such as the molluscs make; they are substantial houses with many chambers into which each animal of the colony can withdraw. There are many species of coral animals. Each constructs a skeleton of a particular shape or color.

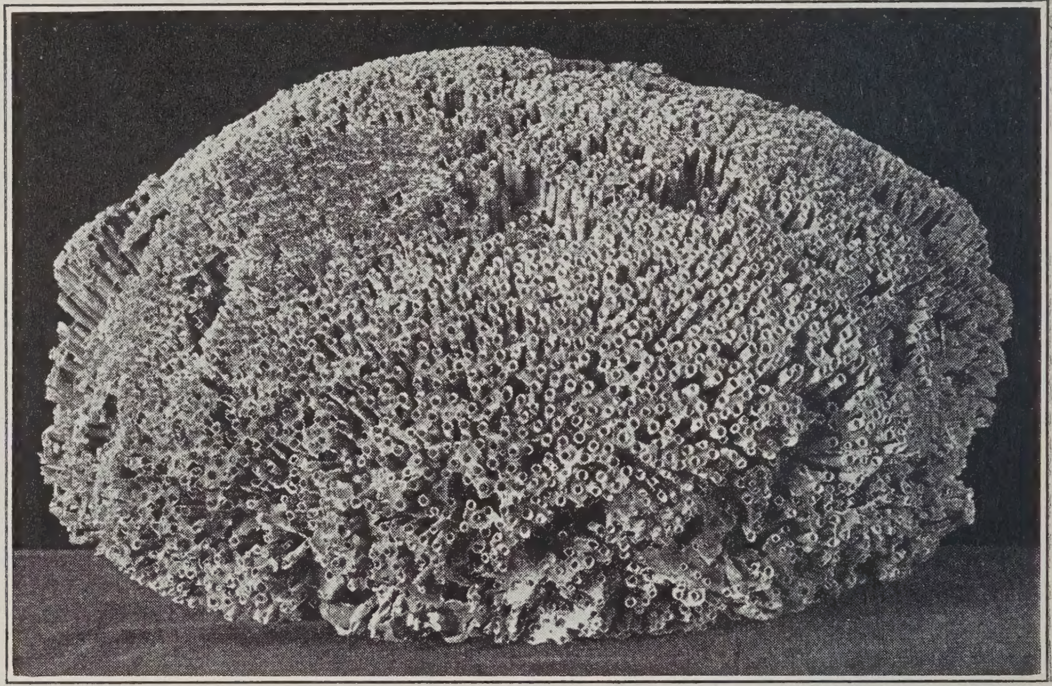
Most corals inhabit the warm waters of tropical seas and it is there that they live in vast colonies containing thousands upon thousands of individuals. When each animal dies it leaves its skeleton behind, and as more and more animals develop throughout a period of many years they slowly but steadily pile up a mass of limestone. After long ages so much rock gathers that a reef or coral island may arise. These are of many shapes but the most curious ones are those that form in the shape of a ring. Reefs are sometimes very long, a thousand miles or more. Bermuda is a group of coral islands. The dazzling white rock on which its houses are built is limestone, composed of the many, many skeletons left behind by little coral animals.



Courtesy Nature Magazine

FIG. 92. Sea anemones showing waving tentacles.

Other relatives of the coral. Grownup coral animals and sea anemones do not swim; they sit, though in their younger stages they can move about. But there are other forms, such as the jellyfish, that never settle down. Like the starfish, they are not fish. But the word "jelly" is not unsuitable. The animal is really jellylike; clear, and transparent, and soft, like jelly which has been cooked with so much water that it has not turned stiff. The body of the jellyfish is almost all water (about 95%). When washed up on the dry beach a jellyfish soon evaporates away until just a shriveled shadow remains.



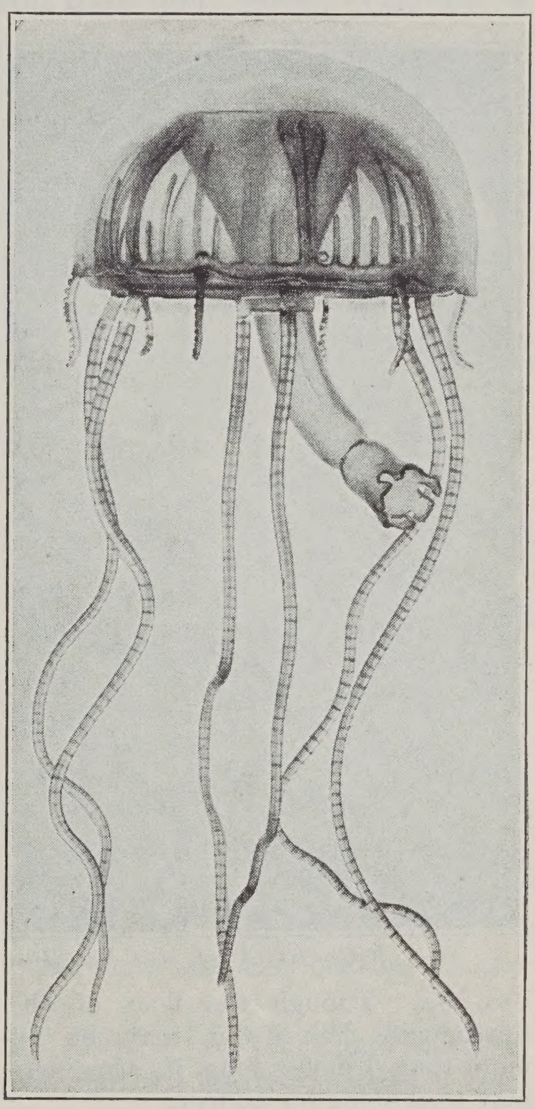
Courtesy American Museum of Natural History

Fig. 93. Organ-pipe coral. The tiny animal within each tube can extend brightly colored tentacles.

Jellyfish look like inverted saucers floating in the water. You must look for the mouth of the jellyfish, therefore, on the lower side. Around the mouth you will find four long waving arms instead of the anemone's forest of stubby tentacles, although there are tentacles, too, hanging like a short fringe from the edge of the saucer-like body. These have stinging cells, so that the jellyfish does not find it difficult to kill its prey.

The jellyfish is not a good swimmer. But it can move through the water by waving its tentacles or by contracting its body. The contraction squeezes water out of the central cavity; this gives the jellyfish a little push in the opposite direction. One of the prettiest sights of the sea is afforded by a school of jellyfish, all contracting together and moving gracefully through the water, but avoid them because their stinging cells can cause discomfort.

One of the most interesting members of this group is the Portuguese man-of-war. Strictly speaking, it is not an animal but a colony of animals. The individuals hang by threadlike structures from a purple-tinted float. The float is filled with gas and serves to support the whole colony. When a number of these animals move along together it looks as though a tiny fleet of submarines were passing by. The float is built by some of the individuals in the colony. Other members do the eating for the group, feeding on fish or smaller animals. Still others act as soldiers and they have good ammunition, too. The stinging cells of the Portuguese man-of-war are exceptionally poisonous. They cause severe pain and swelling in man and may, indeed, result in death for a swimmer caught in a school of these strange animals.

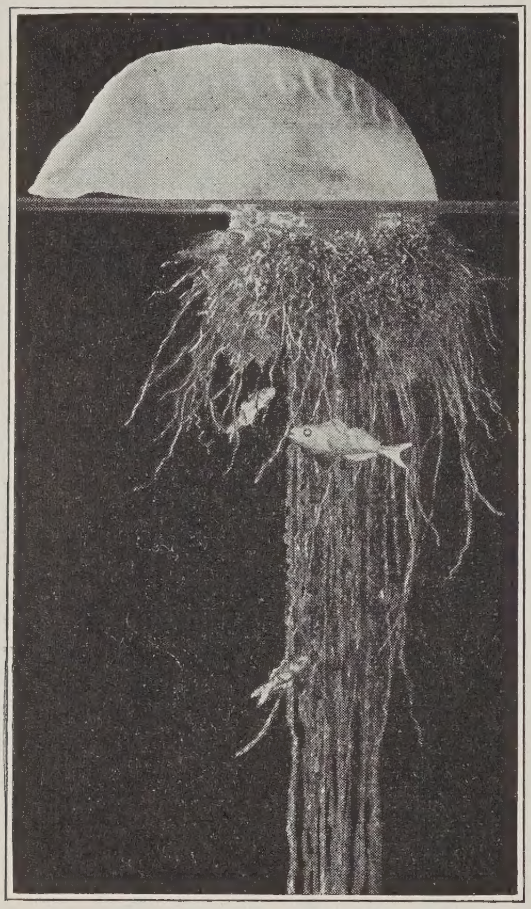


Courtesy Amer. Mus. Nat. Hist.

FIG. 94. This jellyfish has a long tube through which it eats, and a few tentacles around the edge of the umbrella.

Forms you can raise at home. Hydra is common in fresh water aquaria. It is named after the mythological monster with many heads. The tiny Hydra has several long tentacles which must have looked like heads to the observer who first studied the animal through his crude microscope. One species is a bright green, another is brown, but most are a dull gray.

It is possible to see Hydra with the naked eye but you will need a small hand lens to see how it behaves. Then you can see the animal bend gracefully as it sweeps its tentacles through the water in search of food. You need not fear that it will swim away because it is usually fastened to some water plant and stays there for some time. When it does move away it may use its tentacles as hands and turn somersaults, or it may float off in the water. (Fig. 197.)



Courtesy Amer. Mus. Nat. Hist.

FIG. 95. Though the float of the Portuguese man-of-war may be no more than 4 inches long, its streamers may trail along for 50 feet.

What is a coelenterate? It is only the animals included in this phylum that have the unusual stinging cells that shoot out threads tipped with poison; one of the characteristics of the coelenterates (see-len′ter-ates), therefore, is these stinging threads. But it is not difficult to tell that an animal is a coelenterate even though one lacks the microscope needed for seeing the poison threads or cells. For all coelenterates have tentacles surrounding the mouth; and that mouth leads into a central cavity which has no other opening. The animal is almost like a simple sac. It has none of the complex organs found in the higher invertebrates.

5. Animals Riddled with Holes. (*Phylum Porifera*)

The sponge. Every laboratory boasts of a sponge, or many sponges, for washing stone table tops. The manufactured "sponge" of rubber will not do in the laboratory; acids would soon spoil it. But the sponge which was in use long before man had learned to produce rubber resists even strong chemicals. It is the tough fibrous remains of the sponge animal. Just as coral is a product of coral animals, so the sponge is the skeleton of many sponge animals which once lived together in a colony.

They grow fastened to the floor of some tropical sea from which they are torn by dredges or cut loose by divers. The sponge colonies brought to the surface are taken to the dock where workers tread on them to kill them. Then they are strung up until the animals have decayed. After decay has softened the parts, the sponge is washed in water until nothing but the skeleton is left. This is trimmed neatly and may even be treated with chemicals before being sold.

The many-celled animals. The sponges are exceedingly simple in their structure; even simpler than the coelenterates, although the animals of both phyla are not much more than sacs for taking in food. The starfish, the oyster, the lobster, and the insect are far more complicated. They have many body parts, each with a special job to do. And they can do some things which a sea anemone or a sponge cannot do.

You have traveled through most of the animal kingdom, glancing at the fascinating invertebrates as you passed hurriedly by. You have descended from the most complex to the very simple. But there is one great phylum you have not seen, the phylum of microscopic animals. You will read about it next.

Pupil Activities

1. If you examine fresh oysters you may see the beating of the heart.

2. Dissection of a clam is difficult. But if you crack one valve of the shell and remove the pieces gently you will see the mantle, a thin skin next to the shell, and the gills. Can you find the muscles that hold the shells together? Open an oyster and compare its structure with that of the clam.

3. If you are interested in cooking, find out how such animals as snails, octopuses, squids, and sea urchins are prepared for the table. There are many recipes for tasty dishes.

4. The development of the snail is easy to follow if you use a hand lens. Keep several in an aquarium. The eggs are laid in masses, often on the glass. Do all the offspring of snails with right-handed shells have right-handed shells, also?

5. Shell collecting is so popular a hobby that there are dealers all over the world who publish catalogues of both common and rare forms. Encyclopedias contain pictures in color of some of the most beautiful. Make a collection of your own, using a shell book to learn the names of the animals. By exchanging specimens you may be able to get shells from other parts of the country.

6. Biological supply firms prepare starfish for dissection by injecting a colored paste into the water system. If you can obtain one, prepare a dissection for the school museum.

7. Set up an exhibit of the shells of different kinds of echinoderms.

8. The complete story of Darwin's study of the effect of the earthworm on the soil is told in his book, *The Formation of Vegetable Mould.* It is not difficult to read. Prepare a report for the class.

9. Collect some earthworms and keep them in a box of earth with glass sides. Watch them.

10. Dissect an earthworm. Drew's Manual will provide you with directions.

11. Sometimes good cider vinegar contains tiny little roundworms known as "vinegar eels." With the naked eye you can see them moving about. In what respect is their name not well chosen? Study them under the microscope. Other roundworms may be found in stagnant water, wriggling actively, or in the soil.

12. The practice of bleeding patients grew out of mistaken ideas about disease. Read up on them and report to the class.

13. If you follow directions carefully you can maintain a salt water aquarium. Starfish, sea anemones, and mussels will live happily in it if you have plenty of seaweed. The Turtox leaflet (Genl. Biol. Supply House, Chicago) will provide complete directions. You may buy the plants, animals, and sea water from biological supply houses if you are far from the coast.

14. Sea anemones have so many walls of skin inside that they are not easy to study. You can prepare a dissection, however, by cutting the animal in half, either crosswise or lengthwise. Fasten it to a glass plate and preserve in a jar of formalin.

15. There are many theories of coral reef formation. Look them up and report to the class.

16. Hydra can be bought from biological supply houses or collected in fresh water ponds or streams. Place leaves and stems of water plants in a jar with the water in which they grew. Examine them after the water has settled and Hydra has had a chance to recover from the shock of moving.

17. Why does the sponge soak up water?

18. If you are talented in drawing why not prepare a mural for the walls of your classroom, showing examples of animals in each of the phyla from the sponges up to the arthropods?

19. *Summary.* Can you describe each of the large groups (phyla) of the invertebrates other than arthropods and name a few examples of each group? List those you can remember and check by looking at the text. Which of the invertebrates did you find most interesting? Why? Discuss your choice with your classmates.

Good Books to Read

Arnold, A. F., *Sea Beach at Ebb Tide.* Century.

Beddard, F. E., *Earthworms and Their Allies.* Macmillan.

Crowder, W., *Between the Tides.* Dodd Mead. *Dwellers of the Sea and Shore.* Macmillan.

Duncan, F. M., *Animals of the Sea.* Nelson (England).

Fuller, R. T., *Along the Brook.* John Day.

Johnson, M. E. and Snook, H. J., *Seashore Animals of the Pacific Coast.* Macmillan.

Miller, M. R., *The Brook Book.* Doubleday.

Pratt, H. S., *Manual of the Common Invertebrate Animals.* McClurg.

Rogers, J. E., *The Shell Book.* Garden City.

School Nature League, *Bivalves — Clams and Their Relatives.* The League, New York City.

Verrill, A. H., *Strange Sea Shells and Their Stories.* Page.

Webb, W. F., *Handbook for Shell Collectors.* The Author, Rochester, N. Y.

CHAPTER IX

THE "INVISIBLE" ORGANISMS

A great discovery. If modern newspapers had been published in 1676, how exciting would their big black headlines have been on that day when Leeuwenhoek, an amateur biologist, first saw living things through a microscope. Headlines might have read "Scientist Discovers New World" or "Invisible Hordes Besiege Man." Leeuwenhoek actually discovered a new world, the world of the hitherto invisible organisms. His discovery showed man that his planet holds not only the animals and plants to which he had become accustomed but hordes and hordes of different creatures, animals and plants too tiny for him to see with the naked eye. They are all about him; in ponds, in oceans, in the air, on every object he may touch. Gone was the notion that the clear water of lakes was really clear; after Leeuwenhoek's discovery man knew that a whirling, dancing army of little living things might make their home in the water. The water looks clear only because man's eyes are not sharp enough to detect these tiny specks.

Perhaps it is lucky that you must use the microscope to see the myriads of fellow living creatures. If they were visible to the naked eye you would grow dizzy, for they dart and crawl, glide and twirl, ceaselessly, in the water all about you; and, in the air, they dance with the particles of dust which carry them.

The homes of microscopic organisms. Leeuwenhoek first found microscopic animals and plants in rain water which had been standing in a barrel; but then he found them in all kinds of places: in pond water, in decaying substances, and in material scraped from the teeth. When one wishes to look at microscopic living things it is not always convenient to dip water out of a pond, nor is rain water always to be found in a nearby barrel. So biologists have had to learn how to raise these organisms in the laboratory, providing homes for them as one does for white mice or guinea pigs used for experiment. And just as white mice need conditions different from those required by chickens, so the various kinds of little organisms often need different kinds of homes.

But there is one kind of home which suits so many different species of microscopic living things that it is kept in every biology room. It is called a *hay infusion.* It is made by putting dried grass, or hay, into water, which is then permitted to stand. As the hay decays, some of its food materials dissolve in the water, which takes on a brown tint. Whenever water takes up materials in this way it may be called an *infusion.* Many kinds of microscopic creatures will soon be swarming in the infusion for there are always some clinging to the hay which is used; others are present in the water and since the home is well prepared, more and more living things soon make their appearance.

When pond water is lacking, therefore, you may turn to the hay infusion for your first look at the world of microscopic living things. If you are lucky enough to be able to get the use of a microscope you can look forward to many happy hours of discovery.

Many of the microorganisms of the hay infusion are classified as animals; others are plants. Since to you their size is the most interesting characteristic, they have been grouped together in this chapter on the "invisible" organisms.

A giant among microscopic animals. (*Phylum Protozoa.*) One of the commonest inhabitants of the hay infusion is an enormous *microorganism* (microscopic organism), which is just visible to the naked eye as a white speck darting about in the water. You may have heard its name: *Paramecium* (păr-a-mee′see-um). It is an animal.

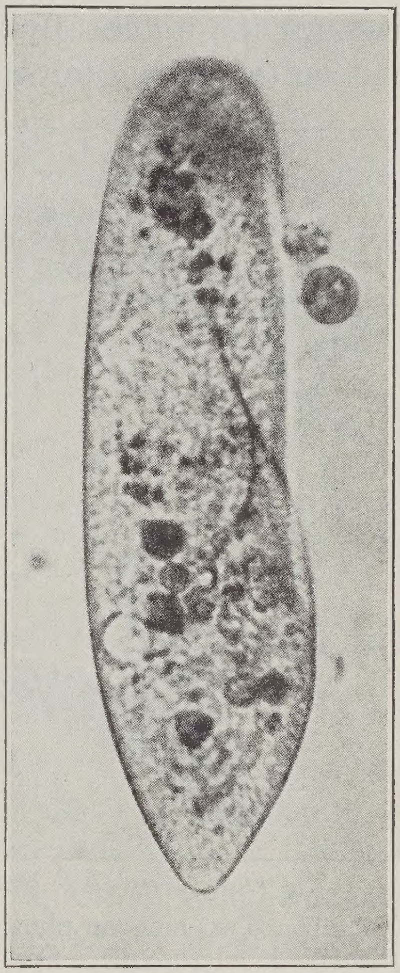
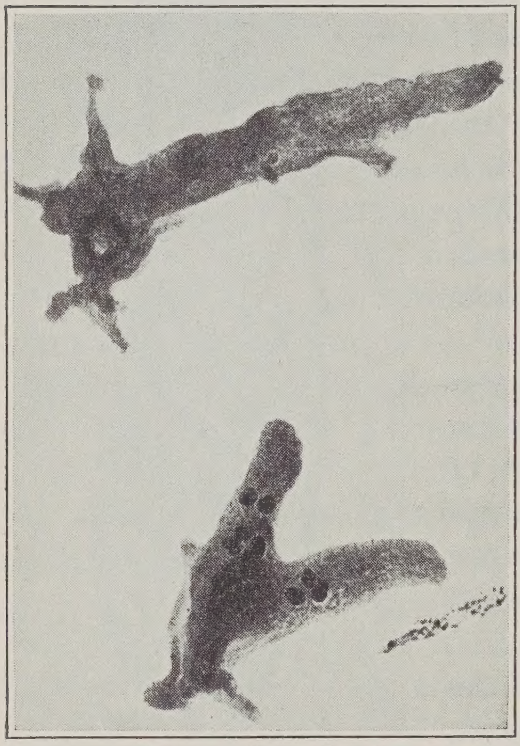


Photo by Hugh Spencer

Fig. 96. Living paramecium photographed through a microscope. The outlines look blurred because of the movement of the cilia.

It is not easy to examine a lively paramecium with the microscope; it moves too fast. But it is possible to catch it in the fibers of cotton or even to thicken the water so that the paramecium pushes its way through with difficulty. Either one of these tricks will show you that the little submarine-shaped paramecium is covered with tiny hairs or *cilia* (sil′ee-a). The singular is cilium. These cilia beat vigorously and thus push the paramecium rapidly through the water. By lashing the cilia hard in the opposite direction the animal can go into reverse. The cilia are arranged in rows diagonally so that as they beat they make the paramecium roll over and over like a barrel at the same time that it moves forward or backward.



Courtesy Genl. Biol. Supply House

FIG. 97. Two amebae photographed through a microscope. Can you see bits of food in the lower one?

As the paramecium rolls over it looks as though part of its cigar-shaped body had been scooped out on one side. This depression, called the *gullet,* leads to a spot, the *mouth.* Long cilia line the gullet; their beat is inward so that any smaller microorganism ill-fated enough to be caught by the current is swept into the paramecium.

The microorganism of ever-changing shape. There is another giant among animal microorganisms which is less frequently seen than paramecium: *Ameba.* Because of its habit of clinging to some solid base instead of darting through the water of the hay infusion, it is difficult to see an ameba without a lens. Ameba is not trim and compact like paramecium, but spreading and shapeless. Its body is soft and jellylike — just a blob of living matter which oozes along from place to place. The living material flows, for a while, in one direction and forms a projection called a false foot or *pseudopod* (sioo′doe-pod). It is a temporary foot which can form on any part of the body; in fact, ordinarily an ameba has several pseudopods at the same time sticking out in different directions. Whenever the material keeps on oozing in one direction the pseudopods at the other end are somehow drawn into the animal; they are not left behind. And so the ameba, by ever changing its shape, crawls along over the surface of some leaf or stem under water.

The pseudopods, very conveniently, are used for feeding too. If some smaller microorganism or other particle of food lies in the ameba's path, false feet flow out above, below, and on all sides of it and join together on the other side. The food particle is then inside the ameba, or, more correctly, the food particle is inside a little drop of water which is inside the ameba, for when the pseudopods join together they enclose a little water too. If the animal picks up some worthless particle like a grain of sand it simply drops it behind as it flows along. At one moment the sand is inside the animal, the next moment it is out.

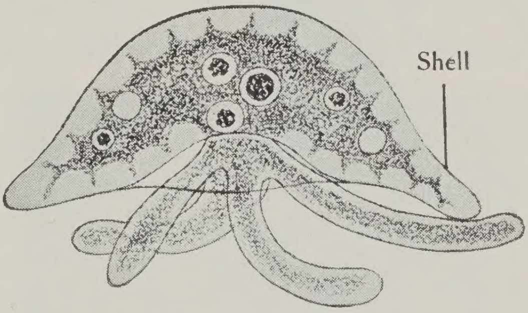


FIG. 98. Side view of Arcella, an ameba with a shell. When seen from above it looks like a doughnut. How does it get its food?

Microorganisms at home. But let us visit the microorganisms in their haunts. The edge of a quiet stream, a little pond, or even a tiny puddle may contain countless individuals. If there are decaying leaves at the bottom you will probably find amebae crawling over them. Nearer the surface may be paramecia and various other kinds of microscopic animals of different shapes and sizes. All of these animals may be grouped together in one phylum, the *Protozoa* (pro-to-zo′a), which means the first animals. Fifteen thousand species of Protozoa have already been named and you may be sure that there are others that have not yet been found and described.

It is a restless life in this sea. Darting and whirling around, the Protozoa bump and jostle one another. One common little form resembles paramecium in shape and size, but it is somewhat flattened and does not roll. A few stiff cilia serve it as legs. Moving these legs in rapid succession, it seems at times to walk through the water; at other times it swims smoothly and swiftly much like the paramecium. Another common protozoan has a delicate bell-shaped body with a long slender stalk by which it attaches itself to tiny particles of leaves or other objects in the water. These organisms often live together in groups or colonies. If you watch them for a moment, you will see a bell snap back suddenly as the stalk coils up like a spring; then the stalk relaxes and the bell floats gently out.

If the water is not too slowly moving, another microorganism will be found. It has one long whiplike hair by which it lashes itself along. And it is different in still another way from all the forms you have met before, for it has bright green spots; and the greenness is caused by the same substance that makes plants look green. Plant biologists, therefore, claim it as a plant. But since it moves actively like an animal and resembles the Protozoa in many ways, animal biologists also have long claimed it as their own. Of course, it does not really matter which it is called, because the names "plant" and "animal," like all other names, are made by man and can be changed at any time. As long as everyone agrees to call it by its scientific name, *Euglena* (yu-glean'a), it makes little difference whether it is described in books on animals or in books on plants.

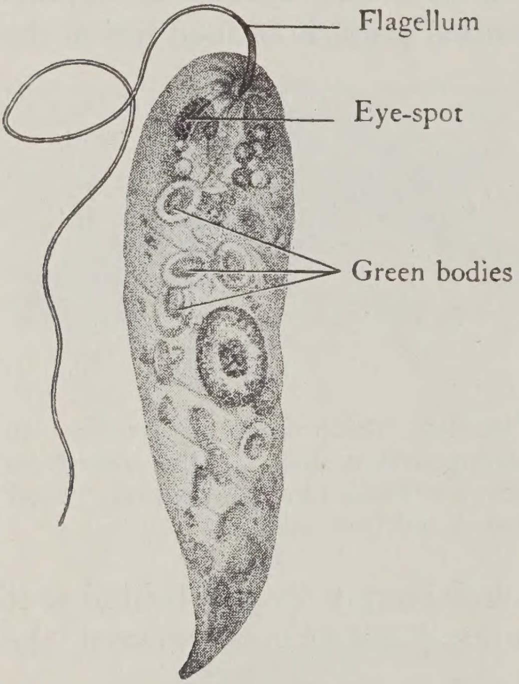
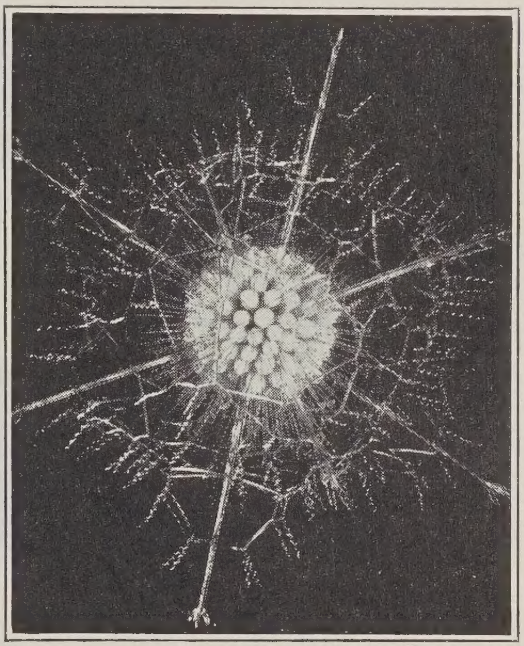


FIG. 99. Euglena is smaller than paramecium. For what does it use the flagellum?

Rain and lightning in the ocean. There are many kinds of microorganisms in the ocean as well as in small bodies of fresh water. Both tiny animals (Protozoa) and tiny plant forms are plentiful. It may be difficult for you to imagine anything as small as a protozoan in a large ocean; but remember they exist there not singly, but in vast numbers. One salt water form which floats near the surface of the sea builds a complicated shell of lime about its tiny body. Now and again, when there is a sudden change in temperature or in other conditions, these organisms are killed. Then, if man's eyes were sharper, he could see the hundreds of thousands of shells fall gently to the ocean floor like raindrops in a gentle rain. Steadily they fall. And they have been falling to the bottom for so long a time that deep beds of lime shells have been formed. Under the weight of the ocean they have become pressed closely together and the mass has hardened gradually into rock. At times, in the distant past, great upward movements of the ocean bed have lifted this rock above the surface of the sea so that now it stands high above the water. The chalk cliffs of southern England and the shores of northern France are made of this limestone rock.

Long ago seamen noted that there were nights when the ocean sparkled with a thousand lights which danced on the waves as the vessels plowed along mile after mile. Now it is known that the churning of the water shows up the light in the body of a tiny organism, called plant by some and animal by others. Its name is *Noctiluca* (nok-ti-loo'ka) which means night light.



Courtesy Amer. Mus. Nat. Hist.

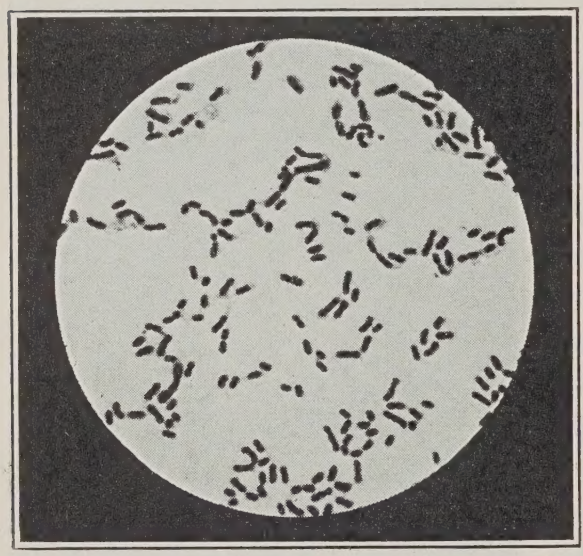
FIG. 100. Skeleton of a Radiolarian. The skeletons of these Protozoa make flint and other hard rocks.

Microorganisms that float in the air. It would probably astonish you to learn how many Protozoa and tiny plants float in the air before your eyes. They may be settling on this page as you read. To be sure microorganisms do not grow in the air but they often float about for a time.

Most of the organisms found in the air are plants. There are many different kinds, which may be roughly separated into two groups — yeasts and bacteria. All of them are extremely small, much smaller than any of the other plant or animal microorganisms you have read about. Both yeasts and bacteria are interesting because, for the most part, they are of great importance to man. Some of them are useful, some harmful.

Microorganisms that help man bake and brew. The yeast plant is so small and so simple that even under the microscope it does not look like much of anything. It is merely a tiny, colorless, egg- or rod-shaped mass which cannot move. It is classified as a plant, but it is not green like an ordinary plant.

There is one special kind of yeast that man has learned to raise for his use just as he raises many larger plants. He grows this yeast plant in vast numbers and then presses millions upon millions of them into one yeast cake. Yeasts are useful because when they settle on sugary liquids they change the sugar into alcohol and a gas called carbon dioxide. This change is called *fermentation.* When man wants to bring about fermentation he often puts yeast plants with soaked crushed corn or other grain. At other times, as when he makes wines, he depends on "wild yeasts" to settle on his grapes and to change some of the sweet fruit juice into alcohol. Wild yeasts float about in the air; that is why you must be careful to keep the syrup bottle tightly closed when you are not using it.



Courtesy Amer. Mus. Nat. Hist.

FIG. 101. These bacteria were photographed through the microscope. They cause pneumonia. Why are they hard to study?

Yeasts, as you may know, are also used in baking. In this case they cause fermentation in the dough but the alcohol evaporates so that you never taste it; the carbon dioxide gas forms bubbles in the solid mass of dough, making it light and porous.

Smaller microorganisms. Most bacteria are so much smaller than yeasts that they are difficult to see and to describe. As a matter of fact there is probably not much to be seen in them.

A few of the bacteria have one or several long whiplike projections, which enable them to swim through the water or other liquid in which they may be found. Some can wriggle along, but most bacteria cannot move about. There are giants and pygmies among bacteria, too, but even the giants are so extremely small that they can be seen only with a powerful microscope.

It is difficult to get a picture of anything as small as a bacterium 1/25,000th of an inch in size. It has been calculated that if the bacterium which causes pneumonia were magnified to the size of a tennis ball, the man attacked by it would have to be about twenty-five miles tall. But bacteria are interesting to man not for the way they look but for what they do.

Pupil Activities

1. To study the organisms in a hay infusion. Boil a small handful of hay and two or three wheat seeds in half a quart of water. Allow it to stand for several days; then add a few drops of pond water. In about ten days you should have a good hay infusion. To slow up the Protozoa for study you can add to your slide a little gum tragacanth (ask for it at the drug store). You will find instructions for the use of the microscope at the end of Unit X. How many kinds of Protozoa do you see? Draw some.

2. If you have a good hay infusion and are skillful with the microscope make daily observations and keep accurate notes. Always take samples of water from different levels in the jar. You will make an interesting discovery in the course of several weeks.

3. How does a paramecium move? Which seems to be its front end? As it swims forward it rolls over. Does it roll clockwise or counterclockwise? Which way does it roll when it swims backward?

4. Perhaps the most fascinating object to watch under the microscope is a large ameba. Do not use a bright light. How many pseudopods do you see? What seems to happen to the particles just inside the tip of a pseudopod at the "front" end of the animal? Does it ever lose a pseudopod? How do you know? How fast does it move? How does it change direction? Does it ever reverse the direction of its movement?

5. Euglena can be kept in an infusion of pond water if you make sure that it receives plenty of light. Look for the eyespot. It is very difficult to see the whiplike hair. What color is the animal?

6. Have you ever thought of owning a microscopic pet? It is really easy. Paramecia make the best pets because they are hardy. By heating a piece of glass tubing soften it until it can be drawn out to make a very narrow tube. Break this narrow tube so that you have a pipette (little pipe) with a narrow opening. Put a slide containing paramecia on a piece of black paper so that the paramecia can be seen with the naked eye as white specks. Catch one by dipping the pipette into the water near it. Draw the pipette out quickly so that you catch only one paramecium. Gently blow the paramecium out on another slide. Add some cool boiled hay water. Then put the slide in a petri dish (ask your teacher). The petri dish must contain a piece of blotting paper soaked in water. To keep your slide dry, put it on two glass rods that lie on the blotting paper. Cover the dish. The next day you should have *two* paramecia. Repeat this process, discarding one of the animals, and keeping the other.

7. If you crumble a small piece of yeast cake into water and mount a tiny drop on a slide you will be able to see the yeast cells under the microscope. A magnification of about 400 times is necessary.

8. How can you find out whether or not there are yeasts in the air? Plan the experiment. Before performing it discuss your plan with your classmates to make sure you are on the right track.

9. Ask your teacher to prepare petri dishes so that you may see colonies of bacteria.

10. Read up and report on the many ways in which bacteria change the world in which we live.

11. In parts of this country the underground rock is limestone. What reason have biologists for saying that these sections were once under the sea?

12. *Summary.* You have read about two kinds of microorganisms, plant and animal. Can you list examples of each? Can you draw simple diagrams of some of them? Can you explain why each is interesting or important?

Good Books to Read

Beavis, G., *The Book of the Microscope.* Lippincott.
Calkins, G. N., *The Smallest Living Things.* University Society.
Conn, H. W., *Bacteria, Yeasts and Molds in the Home.* Ginn.
De Kruif, P., *Microbe Hunters.* Harcourt.
Disraeli, R., *Seeing the Unseen.* Day.
Shipley, Sir A. E., *Hunting under the Microscope.* Macmillan.
Stokes, A. C., *Aquatic Microscopy.* Wiley.
Yates, R. F., *Exploring with the Microscope.* Appleton.

CHAPTER X

THE PLANTS WITHOUT FLOWERS

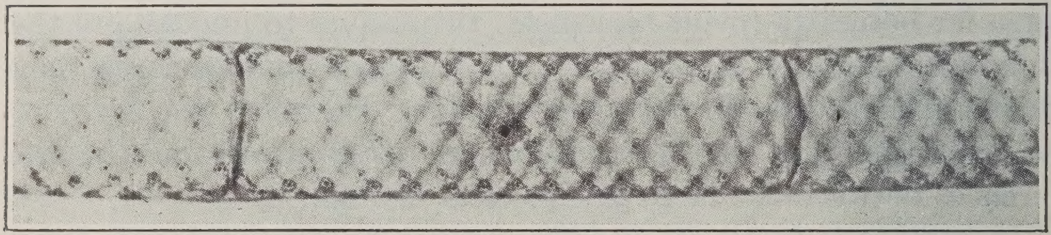
Getting acquainted with the plant kingdom. Getting acquainted with the plant kingdom is perhaps more difficult than getting acquainted with the animal kingdom, because most people know so much less about plants. You tend to take plants for granted without looking at them very closely because they are always around you, making a part of the landscape. And when it comes to classifying them in detail you run into great difficulties. It took a long time for botanists (plant biologists) themselves to understand the differences between the various species of plants and even now they do not always agree on their classification. However, you need not be concerned with the small differences and you will find the differences between the large groups clear enough.

In sorting animals it was convenient to speak of two large divisions, the vertebrates and the invertebrates. Plants are also divided into two large groups, those with flowers and those without.

What is meant by plants without flowers? A flower is not the same thing as a plant, although people sometimes carelessly use the words as though they were the same. The flower, or blossom, is only a part of the whole plant, just as the eye or the heart is merely a small part of the animal. You have seen blossoms on many plants, if not all the year round, at least for a time.

But there are plants that never bear flowers. And they are not the trees and grasses which you may be thinking of. Trees and grasses have blossoms, although you may never have noticed them. To be sure, they are not often brightly colored and sweet scented like the flowers of the rose and the violet. But they exist, so the botanist classifies trees and grasses as flowering plants, together with roses and violets and daisies and many others. The true "plants without flowers" bear no flowers of any kind, and besides, as you will see, they are quite different from the flowering plants in their general make-up.

The simplest flowerless plants. (*Phylum Thallophyta.*) You have already read of some of the simplest plants in the chapter on "invisible" living things. There are many larger plants in this phylum; some, in fact, grow to a great size. You have probably seen some of the simpler flowerless plants out of doors but you may never have thought of them as plants at all. For example, where there is a small pond or a slow-moving stream you may have noticed a green scum on the water. If you poke the scum with a stick you will discover that it is a slippery, dripping, bright green mass. The mass is made of long, tangled threads, each of which has a beautiful, complicated design that can be seen with the microscope only. Each thread, or filament, is a very simple plant which has no root, no stem, no leaves. It is just a living plant thread which grows in the sunny water and at some time becomes food for a water animal.



Courtesy General Biological Supply House

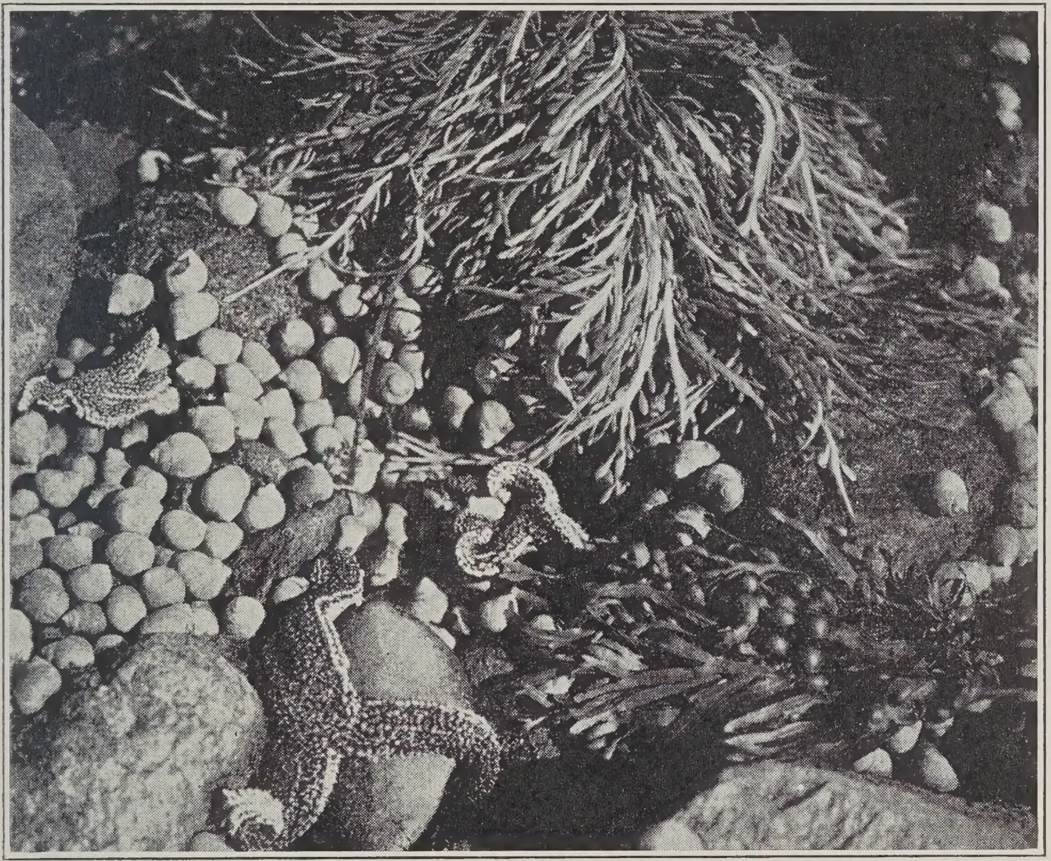
Fig. 102. "Pond scum" or spirogyra is not the only threadlike plant which is found in the green scum of ponds. There are many others that differ in design.

In drinking fountains out of doors you can find a similar plant. It often forms a light green scum along the sides of the bowl.

As in the animal kingdom, so in the plant kingdom, the simplest forms of life are usually inhabitants of water. But a few of the simple plants have taken to land, though only where there is plenty of moisture. The green growth found on the bark of trees, especially on the north side of the trunk, is a mass of simple plants (called *Protococcus*). You may have called it moss; but it is not soft and velvety like a moss. Closely related to it is the so-called "red snow" about which arctic explorers tell. They sometimes find the snow red as though stained with blood. This is caused by the presence of a tiny red plant which does not seem to mind the cold, for it grows directly on the snow.

The simplest flowerless plants, those called thallophytes, are quite different in their make-up from the ordinary plants with which you are familiar. They not only lack flowers but they seem to have no true stems or leaves or roots.

Larger thallophytes. There are other thallophytes that are much more easily studied. They are the large forms that grow in salt water. Some, like the common brown seaweed called the rockweed (or *Fucus*), fasten themselves by suction to the rocks in the region between the tides. When the tide goes out their thick bodies can hold enough moisture to keep them alive. And they are tough enough to stand the pounding of the surf.



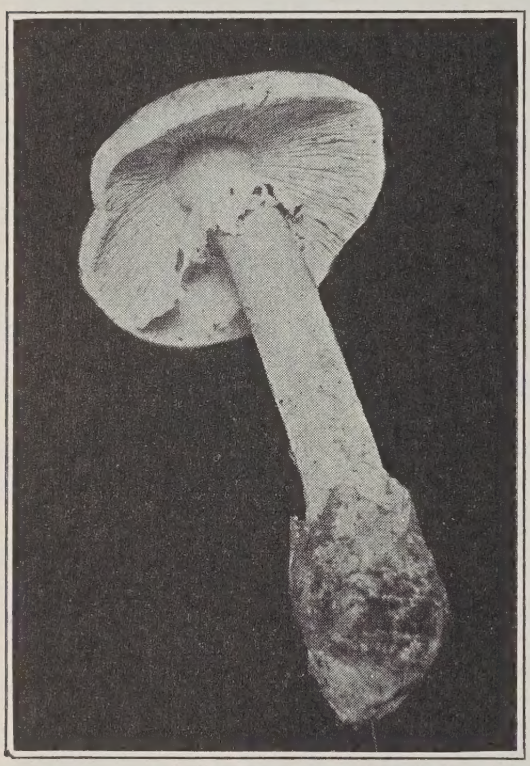
Courtesy American Museum of Natural History

FIG. 103. This is a common sight for those who live near rocky shores. Do you see the strands of rockweed? What animals do you recognize?

Some brown seaweeds, like the kelps, form a forest of strange-looking plants out in the deeper waters. The plant often reaches a length of fifty yards and some have been described of twice that length. Kelps are gathered in large amounts off the coasts of

Ireland, France, and elsewhere and burned to yield iodine and a substance used for glassmaking.

Other seaweeds float near the surface in the open sea. You may have seen pieces of the green sea lettuce (*Ulva*) which have been washed ashore and caught on the sand or rocks. At greater depths live red seaweeds, which are usually delicately branched plants much smaller than the kelps. They, too, are used as a source of iodine and they serve as food as well. The agar-agar which the drug store sells and which the biologist uses in his experiments is prepared from a red seaweed found off the coast of Japan.



© *P. Blakiston's Son & Co., Inc.*

FIG. 104. In many ways this deadly Amanita looks like the common mushroom bought in the markets. Some mushrooms are brightly colored.

Two distinct groups of thallophytes. You have just read of various kinds of thallophytes, the very simple spirogyra and the larger and more complex seaweeds. Biologists find it convenient to speak of three different kinds of seaweeds: the brown, the red, and the green. But they have found the same green coloring matter in all of them. It is merely hidden, in some cases, by the deeper red and brown. All these plants belong to one group of thallophytes known as *Algae* (al′jee). An alga (al′ga) is a thallophyte or simple plant that contains green coloring matter.

There is another group of thallophytes. The plants in this group lack the leaf green color. They are known as *Fungi* (fun′-jy). You have already read about some of the fungi: the yeast and bacteria. You have met some of the larger fungi out of doors: the mushrooms and toadstools. There are other fungi of which you will read later.

Mushrooms and toadstools. The biologist speaks only of mushrooms. But other persons sometimes use the name toadstool for those species that must not be eaten. There are many that are poisonous but about one half of all the various kinds of mushrooms make good food. However, the various kinds are often so hard to tell apart that no one but an expert should decide which can be eaten. Cases of mushroom poisoning, some of which are fatal, are not uncommon. The most deadly of the mushrooms is probably one of the amanitas. It looks much like some of the forms that are good to eat. This fungus was responsible for the death of one of the early Tsars, Peter the Great's father, and has no doubt killed many people in other parts of the world of whom history does not tell. Snails feed on it without harm.

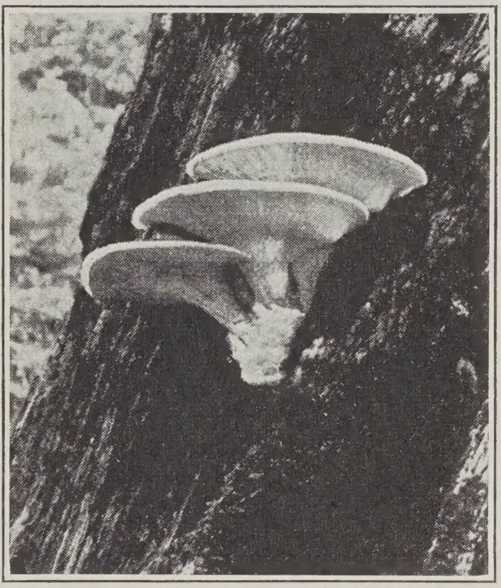

Courtesy U. S. Forest Service

FIG. 105. The bracket fungus is related to the mushrooms. It injures the tree on which it grows.

Mushrooms live only where it is damp; some grow with amazing rapidity. The well-named stinkhorn mushroom has been known to grow six inches in two hours! Most are small, but some attain a weight of more than thirty pounds. The puffballs, which are globe-shaped mushrooms without a stalk, may grow to be several feet in diameter.

Fungi you do not like. If you live where the air may become moist during a long rainy spell, the bread in the breadbox sometimes grows moldy. You undoubtedly know the moldy, musty smell. No one likes it and so the bread is thrown away. The peculiar odor belongs to a fungus plant known as a *mold.* If you give the mold a chance to develop and then examine it closely you will see that what at first looks like an ugly mass is really a very delicate plant. In fact, the bread may serve as a garden for several species of beautiful mold plants. The commonest one, known as the bread mold or *Rhizopus* (ry'zo-pus), consists of a miniature jungle of glistening white threads. Some of the branches of these closely interwoven threads rise far from the surface of the bread, as much as two inches. Each branch is like the finest thread of silk; at its free end it has a tiny black ball, so that at first glance the whole mass of threads looks gray and sooty.

There are some mold plants that look like patches of bright blue-green felt; others are salmon pink. In these the threads are shorter and even more interlaced so that without a powerful lens you cannot see separate threads at all.

Molds of various kinds grow on different foods. Some species are humble in their tastes and content themselves with pieces of old woolen cloth or the leather of old shoes. But they do not find that very nourishing and they remain stunted in their growth. In common speech such stunted molds are spoken of as *mildew.*

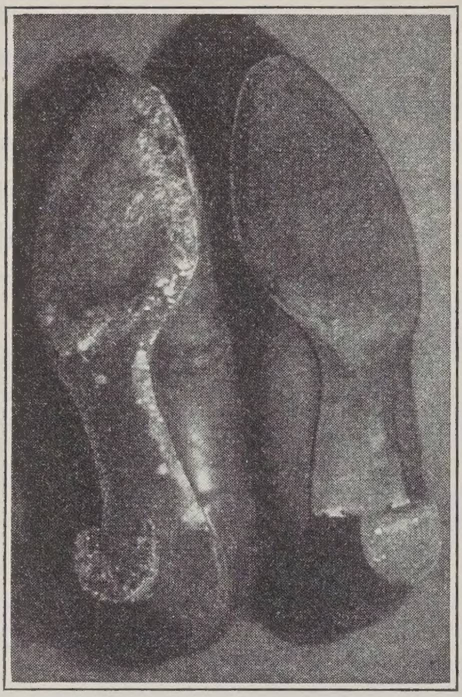


Photo by H. Schneider and J. Schwartz

FIG. 106. One shoe had been kept in a damp, the other in a dry place. Can you explain what happened?

A plant that is both alga and fungus in one. Strictly speaking, this "plant" is two separate plants, one an alga, the other a fungus, but they are so closely combined that they look like one plant. The combination is called a *lichen* (ly'ken). Being composed partly of a green plant and partly of a colorless plant, it looks grayish or yellowish green. You have often seen lichens in the woods, on rocks or logs or trunks of trees. Some grow in big patches on the ground or hang in threads from the limbs of trees. In that case you may have thought the lichen was a moss; in fact, one species is even wrongly named "reindeer moss." But its

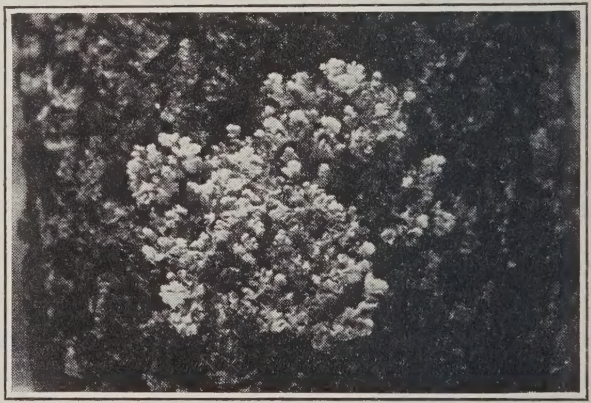


Photo by H. Schneider and J. Schwartz

FIG. 107. A gray-green lichen (Parmelia) on an oak tree.

color and its texture give it away; for it is not really green and it feels rough and harsh as lichens do.

Lichens are extremely hardy plants; when all else has been killed by the cold they still survive. Thus they serve as food for grazing animals of the arctic zone, such as reindeer. Some species of lichens are eaten by man. They are interesting chiefly, however, because of the way in which the alga and the fungus live together.

The second large group of plants. (*Phylum Bryophyta.*) This group includes the *mosses*. They look somewhat more like the plants you are accustomed to see all about you. For one thing, most of them live on land. For another, they are always green and like properly behaved plants are anchored to the soil. Each plant has a stem and leaves. But all these parts are very small, for mosses are rarely more than a few inches high.

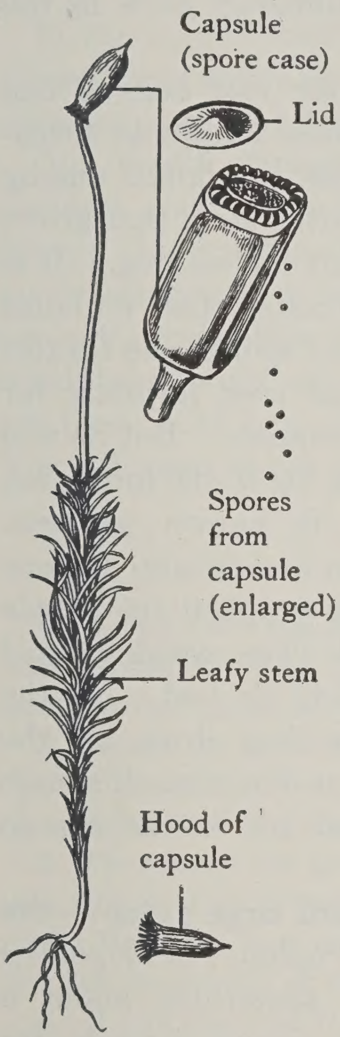


FIG. 108. Most moss plants look more or less like this one. The capsule plays a part in reproduction. What does it contain?

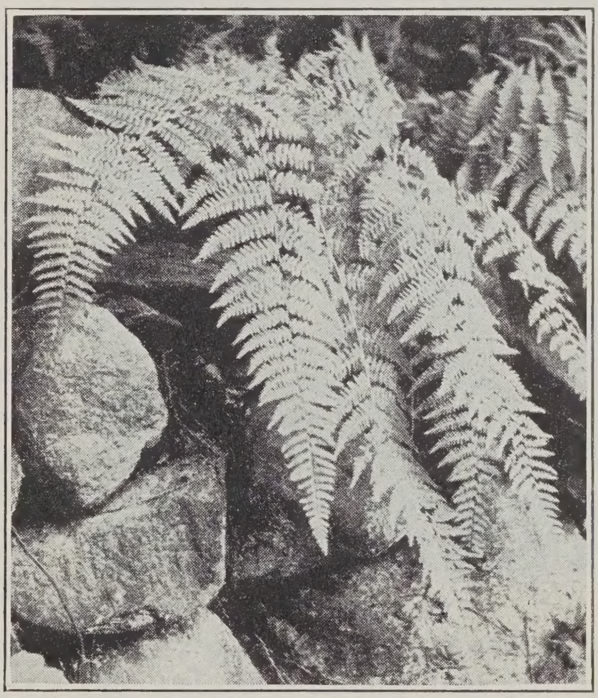
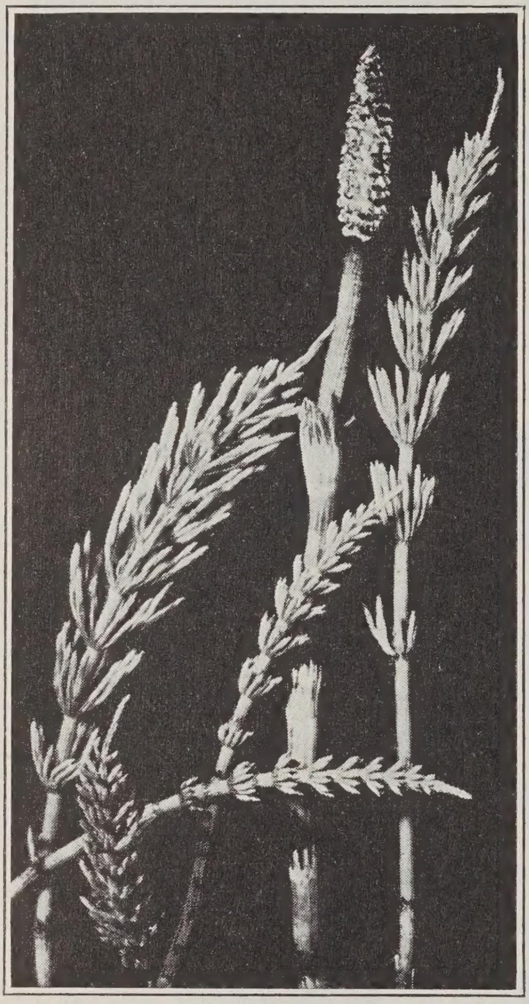


Photo by H. Schneider and J. Schwartz

FIG. 109. The hay-scented fern more often stands upright. Not all ferns have leaves as finely divided as this.

Most mosses form a rich green carpet over the forest floor; they feel pleasantly soft and velvety under foot but unless you stoop to examine them more closely you do not see the beauty of each individual plant. Since they need large amounts of moisture they customarily grow in the woods.



Courtesy Brooklyn Botanic Garden

Fig. 110. The "scouring rush" so often growing near railroad tracks is a relative of the fern. It is harsh and gritty to the touch. Its name tells you how it was once used.

There are vast bogs of one kind of moss known as *sphagnum.* This is a giant among mosses with a stem that grows to be many inches long. It is so constructed that it holds water like a sponge and for this reason was used formerly for dressing wounds. But its real usefulness lies in the formation of what is known as *peat.* Peat bogs in northern Europe have long supplied the people with fuel when wood or coal were not to be had. As the sphagnum bog dries up the peat is cut out in small square pieces and laid in the sun to bake.

The third large group — the ferns. (*Phylum Pteridophyta.*) There is something about a fern that pleases the eye; for that reason you have all noticed ferns and usually recognize them when you see them. They have been cultivated, too, so that they are often seen in homes and gardens. Most species, like the mosses, need moisture and thrive best in the shade of forest trees. There are almost four thousand different species growing in many parts of the world. Some, like the sensitive fern, have escaped to the edge of the forest; a few, like the bracken, have marched out into sunny fields. They are less timid and retiring than the mosses. Many of them are hardy and sturdy plants with strong roots that dig down into the soil; they have stems that lie underground and may extend for many feet just underneath the surface of the soil. Unless you try to dig up ferns you do not see these stems.

In the tropics ferns grow to a much greater size and some develop strong stems above ground. In fact they may grow as trees sixty or more feet high.

Our march through the plant kingdom. Starting with the simplest plant forms there have passed in review three separate phyla: the green and nongreen thallophytes, which do not look much like plants at all; the mosses; and lastly the ferns. Most are quite unfamiliar to you although many of them are common inhabitants of the earth. The plants you are best acquainted with are those that have flowers. They belong to one large phylum. You will read about them next.

Pupil Activities

1. If you have the use of a microscope you will enjoy exploring the water collected from the surface of various ponds. You can easily recognize Spirogyra, and you will find a number of other threadlike plants.

2. Scrape the green substance off the bark of a tree. On a slide tease apart the material you gathered. Mount it in water. How does this plant differ from the threadlike plants?

3. Frequently the green plant growth is found on only one side of a tree. Does it grow most commonly on the north, south, east, or west side? Does this seem to show anything about the conditions most favorable for the growth of this plant?

4. If you live near the shore, make a collection of seaweeds.

5. Look up the subject of the economic importance of seaweeds and report to the class.

6. Besides their special uses to man, of what use are seaweeds in the world?

7. Study the common field mushroom, *Agaricus*. This can easily be bought at most seasons of the year. What do you find on the lower side of the cap?

8. If you live in the country, can you present any evidence that mushrooms grow quickly?

9. Look through the titles of your State publications as well as those of the United States Department of Agriculture for bulletins on mushroom growing. Send for some and report. If you have a cellar with the right conditions you might try raising some.

10. Making a mushroom collection is not very satisfactory but collect as many as you can to identify them. If you are skillful at modeling or drawing you can add to your class museum.

11. To become acquainted with various kinds of molds you need only put out food and they will come to you by themselves. On pieces of moist white blotting paper in bowls, expose some bread, apple, lemon, cheese, and other kinds of food. Cover the bowls and keep them at room temperature. Keep the blotting paper moist. After several days begin to observe closely at short intervals. Describe what you see. Compare with the results obtained by your classmates. Do certain kinds of molds seem to favor certain foods? Where do the molds come from?

12. Bring in from the woods examples of mosses, lichens, ferns. Can you tell them apart? Ask your teacher to help you. In some cases it may be difficult for you to decide whether they are plants without flowers unless you see them at all times of the year.

13. Ferns are common and easy to press. When carefully mounted they make beautiful specimens. They are also relatively easy to identify.

14. Could you make a simple key to the ferns found in your vicinity? Look back to the chapter on the Sorting of Animals and Plants.

15. *Summary.* If there are some members of the class who have collections of seaweeds, or information on algae to present, some who have raised molds and mildews, or who have studied mushrooms, they could summarize what you should know about thallophytes. Others perhaps could report on mosses. Some, surely, could give information and show specimens of ferns. You will then, as a class, have summarized this chapter, and you will have made a small beginning toward learning to know the plant kingdom.

Good Books to Read

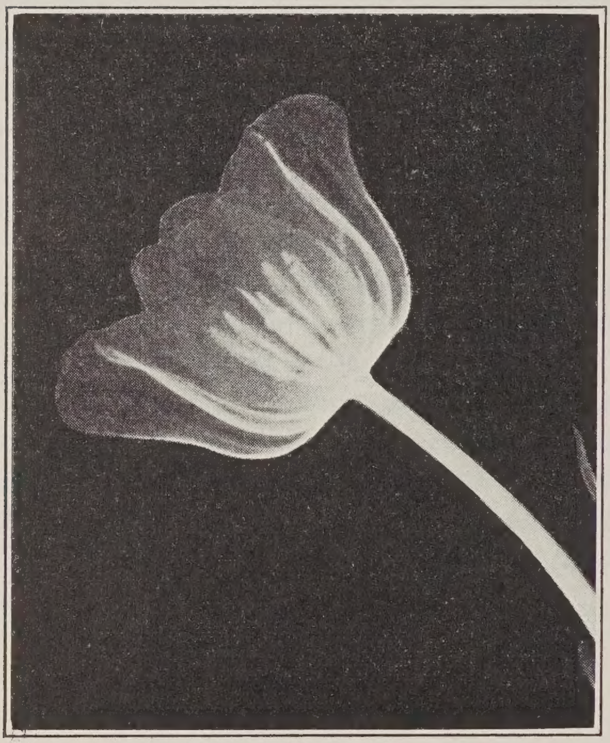
Arnold, A. F., *Sea Beach at Ebb Tide.* Century.
Clute, W. N., *Fern Allies.* Stokes. *Our Ferns in Their Haunts.* Stokes.
Conn, H. W., *Bacteria, Yeasts and Molds in the Home.* Ginn.
Dunham, E. M., *How to Know the Mosses.* Houghton Mifflin.
Grout, A. J., *Mosses with a Hand Lens.* The Author, Staten Island, N. Y.
Marshall, N. L., *The Mushroom Book.* Doubleday Doran. *Mosses and Lichens.* Doubleday Doran.
Morgan, A. H., *Field Book of Pond and Stream.* Putnam.
Parsons, F. T., *How to Know the Ferns.* Scribner.
Rolfe, R. T. and F. W., *The Romance of the Fungus World.* Lippincott.

School Nature League, *Club Mosses and Horsetails* (*The Fern Allies*). *Fungi. The Lichen Clan. Mosses and Lichens. Six Common Evergreen Ferns.* The League, New York City.
Thomas, W. S., *Field Book of Common Mushrooms.* Putnam.
Tilton, G. H., *The Fern Lover's Companion.* Little, Brown.
Williams, S. H., *The Living World.* Macmillan.

CHAPTER XI

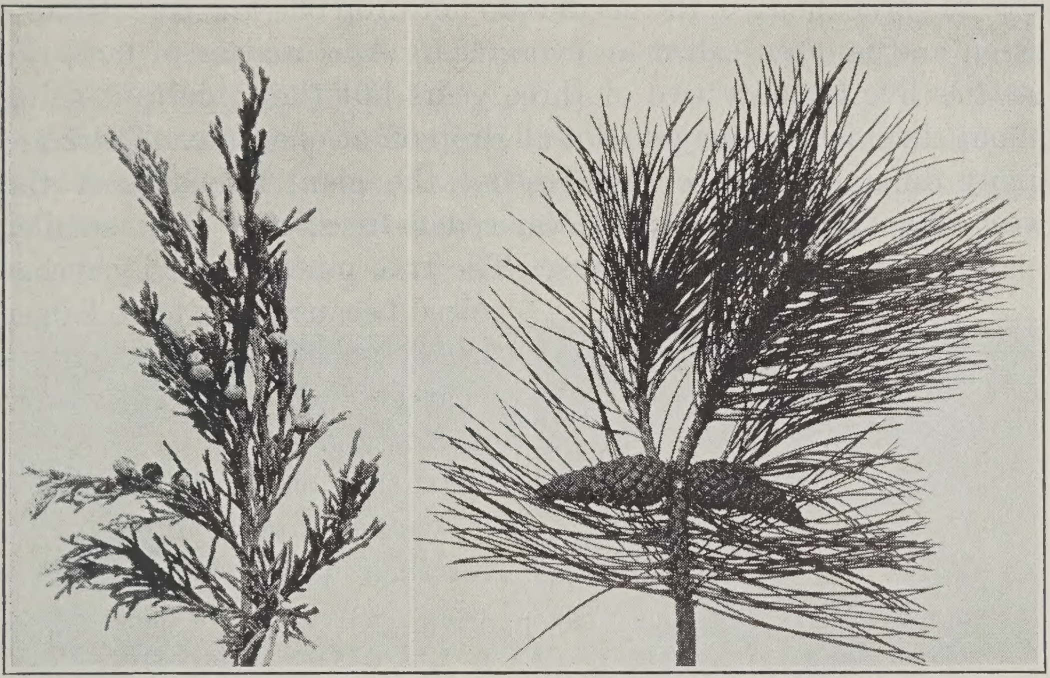
THE FLOWERING PLANTS

The characteristics of flowering plants. (*Phylum Spermatophyta.*) Of course, all flowering plants have blossoms of one sort or another, which in time produce seeds. But they have another characteristic which is not shared by any of the simpler plants except the ferns: they have well developed roots, stems, and leaves. There is great variety in the size and appearance of these parts, as well as in the blossoms, as you can imagine when you hear that there are more than 125,000 different species of flowering plants. Some have a stem that is soft, grows rapidly, and dies at the end of the year. Because of this they cannot attain a great size. They are the *herbaceous* (her-bay'shus) plants. Other flowering plants have stems that are woody and tough. If they have one main stem they are trees; if they have several equally thick stems arising from the ground, in which case they usually do not grow very tall, they are called *shrubs*. The differences between the tiny grass plant and the oak tree may seem very great to you but the botanist finds the resemblances to be more important; so he puts flowering plants, unlike as some seem to be, into one phylum.



Courtesy General Electric X-ray Corp.

FIG. 111. This X ray of the tulip blossom shows the parts of the flower.



Courtesy Amer. Mus. Nat. Hist. *Courtesy Brooklyn Botanic Garden*

Fig. 112. Both the red cedar (left) and the pine (right) are cone-bearers. In the red cedar, however, the cone is hidden within a so-called berry. Compare the needles of the two trees.

This phylum includes some plants that you would not think of as flowering plants at all; those that bear cones. Although a pine cone does not look much like a blossom to you, the botanist considers it one. However, it is different enough from an ordinary flower to make necessary a division of the phylum into two groups: one group of cone-bearers and a second group of plants that have flowers easily recognized as such.

The cone-bearers — one division of the flowering plants. The leaves of cone-bearers are usually hard needles or tiny scalelike leaves which can withstand the winter drought (lack of moisture) and cold. Therefore, when the ground freezes and little water is

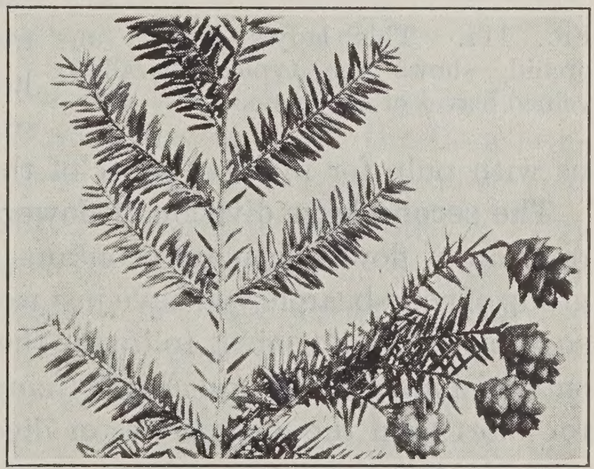


Photo by Mary C. Dickerson

Fig. 113. The hemlock. How does it differ from the pine and the cedar?

able to enter the tree, the needles do not drop off; the tree remains green and is often called an evergreen. As a matter of fact, the needles live for only two or three years but the important thing about them is that they do not all drop off at one time. There are many different kinds of evergreens: the giant redwoods of the west, pine trees, hemlock trees, cedar trees, and even smaller plants or shrubs like the yews. The true pines are easily recognized because they have longer needles than any other cone-bearers, and their needles grow in clusters.

In the temperate zones the evergreens are of great value for their wood. Because their wood is not so hard as that of most of the other trees that grow in the forests they are often known as softwood trees. Most of them have a very sticky sap which has a strong, peculiar odor; it is known as *resin*. Partly because of the resin and partly for other reasons the wood burns very quickly and is not very satisfactory as firewood. But the evergreens supply most of our lumber. And they are of great importance, too, in furnishing us with pulp for making paper of the cheaper grades.

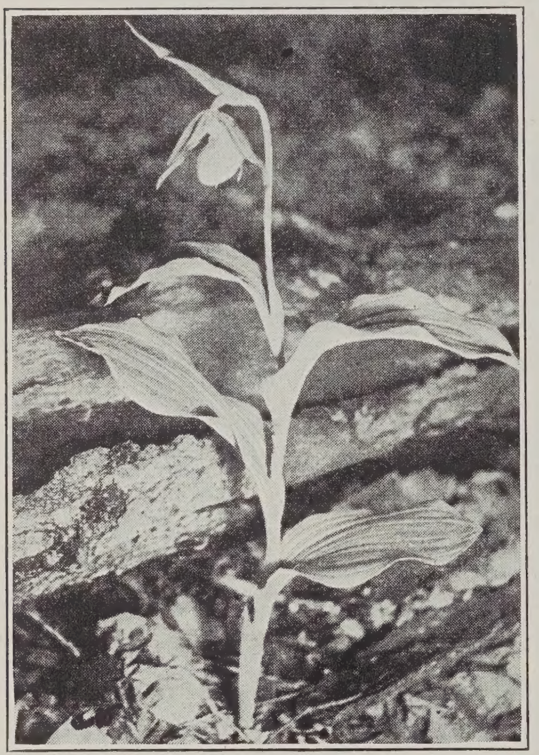
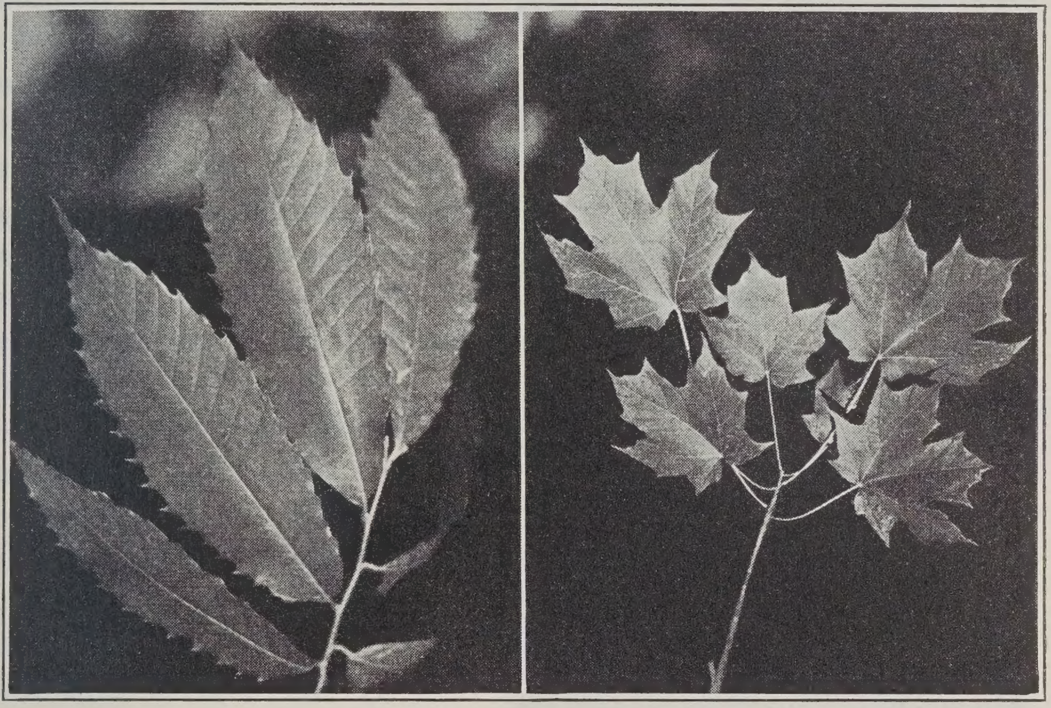


Photo by Frank Gehr

Fig. 114. This lady's slipper, an orchid, shows the typical parallel-veined leaves of the monocot.

The second large division of flowering plants. The second large division of flowering plants contains many more species than the group of cone-bearers you have just read about. And since there are so many it is convenient to divide them again into two still smaller subdivisions, the *monocotyledons* (mono-cot-i-lee′dons) or monocots for short, and the *dicotyledons* or dicots. It is easy, for the most part, to tell these two groups apart. The leaves of the monocotyledons have many long veins running from one end of the leaf to the other and close to one another. The leaves of the dicotyledons have veins that form a network with a few principal veins. You may recognize several other differences if you look at the two kinds of plants carefully.

Of course, the monocots and the dicots are further subdivided into families. There are more than two hundred and forty families in the group of dicotyledons alone and each family contains, as a rule, many species. Only a very few can be mentioned here.

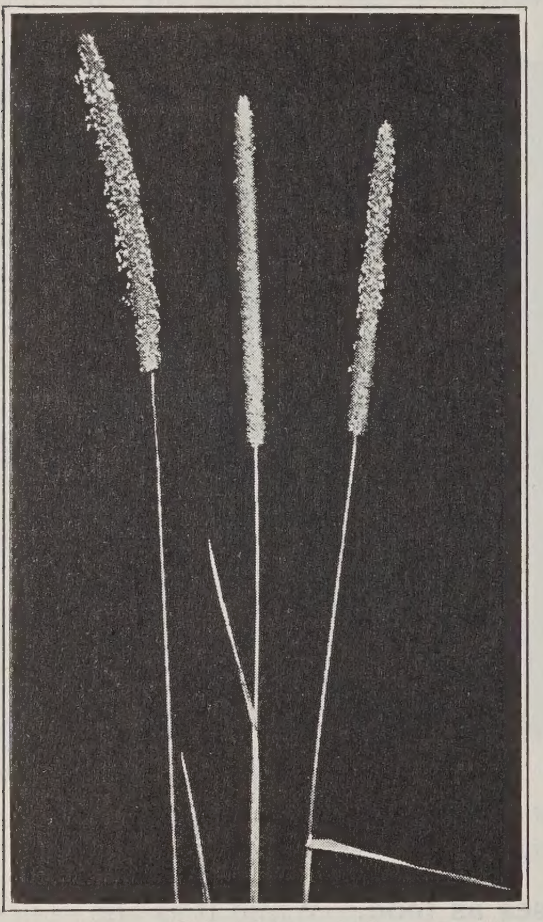


Photos by H. Schneider and J. Schwartz

FIG. 115. The leaves of the chestnut tree (left) show one type of dicot veining; the leaves of the sugar maple (right), another. How do they differ?

Monocotyledons that man uses as food. While it is the cone-bearers that help supply your reading materials, it is the monocotyledons that provide much of your food. This may astonish you, for many of these plants are small and unimportant looking. But what they lack in size they make up for in numbers, for they grow side by side in endless stretches of field and meadow. All the many kinds of grasses are monocotyledons, as you can easily see for yourself if you examine their leaves. They furnish food for the cattle, sheep, hogs, goats, and other grazing animals which man raises to give him meat or milk.

Man uses grasses of various kinds as food plants for himself. The "cereals," or grains, such as wheat, oats, barley, rice, and corn, are close relatives of the small wild grasses of your meadows and lawns. The grains have been used and cultivated for many years. The cultivation of these plants has gone on so successfully that over three billion bushels of wheat alone are now produced in the world each year. When you realize that it is only the small kernels or seeds of the plant that are gathered to fill the bushel baskets you can appreciate how many acres must be planted with wheat.



© *P. Blakiston's Son & Co., Inc.*

Fig. 116. Most grass plants have tiny, inconspicuous flowers. This timothy grass has large numbers on each spike.

In the tropics there grows a giant grass, the sugar cane. There are various amateur sugar manufacturers among plants but the sugar cane is a true professional. It makes much of the sugar eaten by man.

Other species of monocotyledons growing in warm climates, but looking more like trees, are the date and cocoanut palms and the banana plants. Their fruits serve as the regular food of the natives and are shipped in vast quantities to other parts of the world.

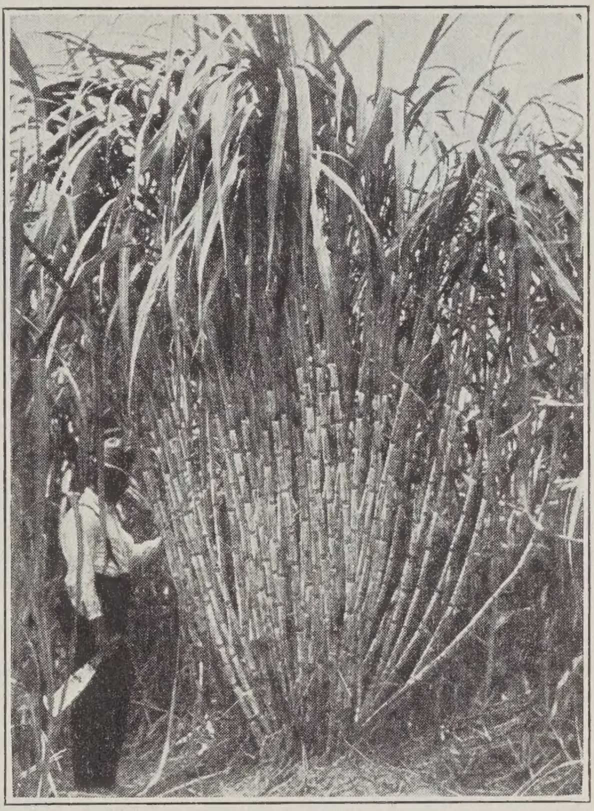
Monocotyledons famous for their blossoms. Several families of monocotyledons are of interest for their beautiful flowers. The orchids which grow wild in the tropical forests have been cultivated to fill the florists' windows with blossoms of most unusual shapes. There are many species in the orchid family, some of which grow in our fields and woods.

Another group is the large lily family which includes, besides the many lilies, the wild onion and, among others, the famous tulip. In ancient Persian history one reads of a "tulip grower" to the Grand Vizier. From the East the tulip made its way to the gardens of

Europe as early as the sixteenth century. Then came a fad for raising and selling tulips; more than fifteen hundred dollars was paid for a single bulb. Fortunes were made and lost in tulips. Though the craze died down, raising tulips is still an important industry in Holland.

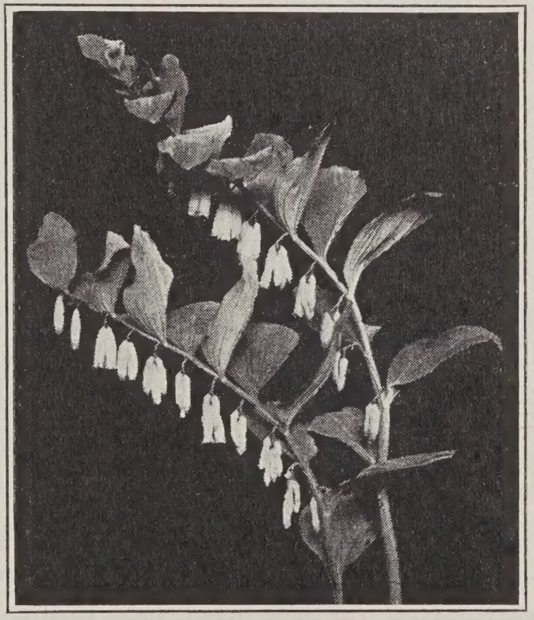
Dicotyledons that grow as trees. In the temperate zone, all native trees, except the cone-bearers, are flowering plants with net-veined leaves; that is, they are dicotyledons. Almost all these trees shed their leaves at the end of the season. They are *deciduous* (de-sid′you-us). Instead of cones, they have blossoms, although these are, in most cases, so small and so hard to see that you might have difficulty in detecting them. These deciduous trees are rather generally referred to as "hardwoods" by the forester and lumberman.

There are several families of trees widely spread through large portions of the United States; you are probably familiar with most of them. If you can recognize the oak, the maple,



Courtesy U. S. Bureau of Plant Industry

FIG. 117. Notice the characteristic rings (nodes) of this sugar cane. It is an enormously overgrown grass. How tall is it?



Courtesy Brooklyn Botanic Garden

FIG. 118. The true Solomon's seal (Lily family) grows in the woods.

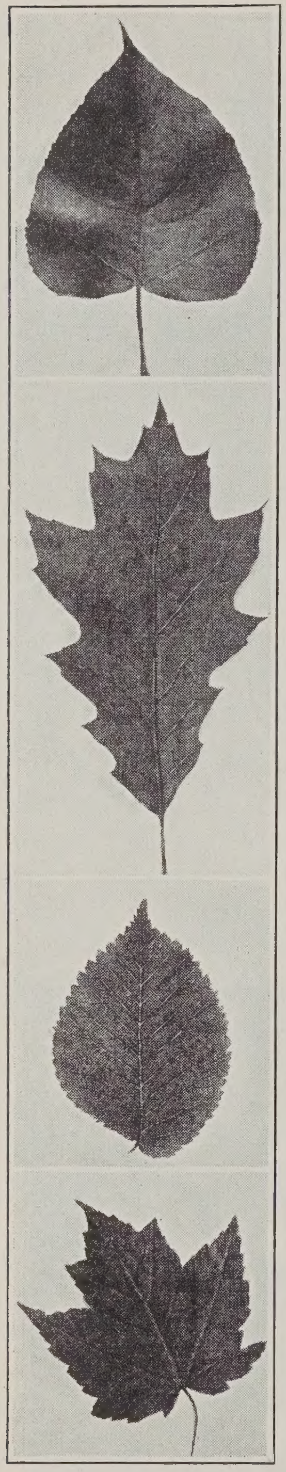


FIG. 119.
a. Poplar leaf

Courtesy Brooklyn Botanic Garden

b. Oak leaf

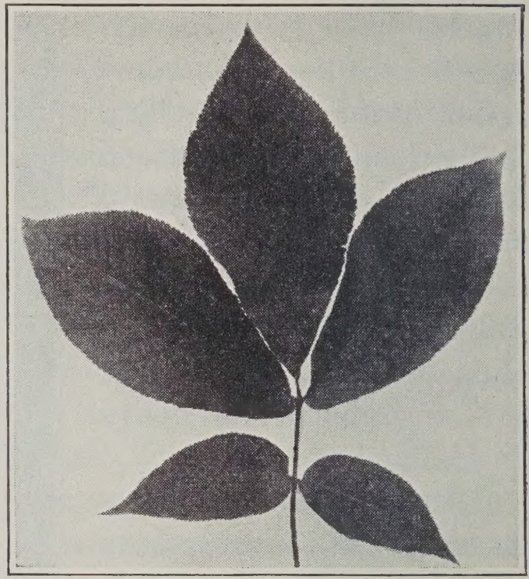
Courtesy American Museum of Natural History

c. Elm leaf

Courtesy American Museum of Natural History

d. Red maple leaf

Courtesy American Museum of Natural History

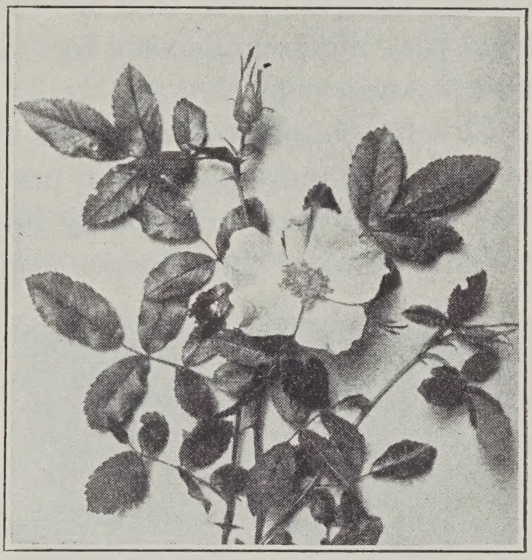


Courtesy Brooklyn Botanic Garden

e. This shagbark hickory leaf is a compound leaf. It has five leaflets. Some compound leaves have a larger number of leaflets.

the elm, and the hickory or walnut you are acquainted with at least one member of each of four prominent tree families.

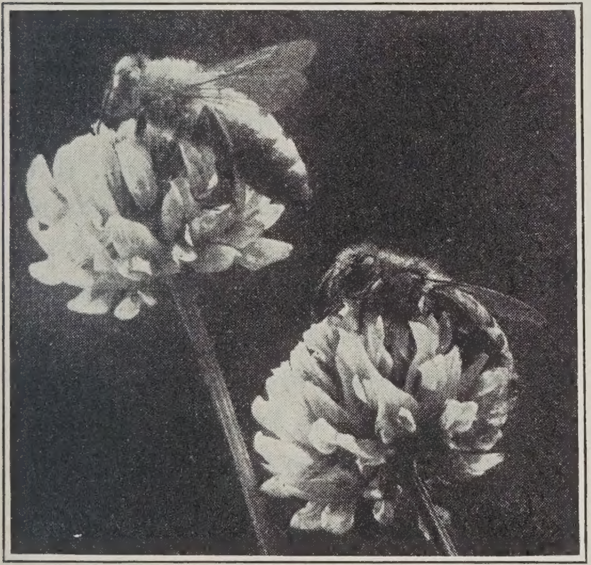
Another family that many of you will know includes the willows and the poplars. You often see willows lined up along the banks of streams. In dry, otherwise treeless regions a group of poplars always is a sign of water trickling through the soil. Their wood is unusually soft and is therefore much used for paper-making. They all grow very rapidly and for that reason certain species of poplars have been much used for planting along city streets. But they are really not well suited for this for it has been found that even a large tree will sometimes break in a heavy storm and, what is worse, their roots search so eagerly for moisture that they squeeze into water pipes and clog them.



Courtesy Brooklyn Botanic Garden

FIG. 120. The wild rose. How does it differ from cultivated roses?

The rose family. Some people have the idea that trees must be put into families by themselves apart from the smaller plants. But there are some families that contain species ranging in size all the way from a small, soft-stemmed herb (erb) to a good-sized shrub or tree. One such family is the rose family, known for its beautiful, sweet-scented flowers and its delicious fruits. This family includes, among many other plants, the trees that give us the pear, the peach, the plum, and the apple; it includes also the shrubs which bear the raspberry and the blackberry, the bushes which bear the rose, and the still smaller, modest strawberry plant.



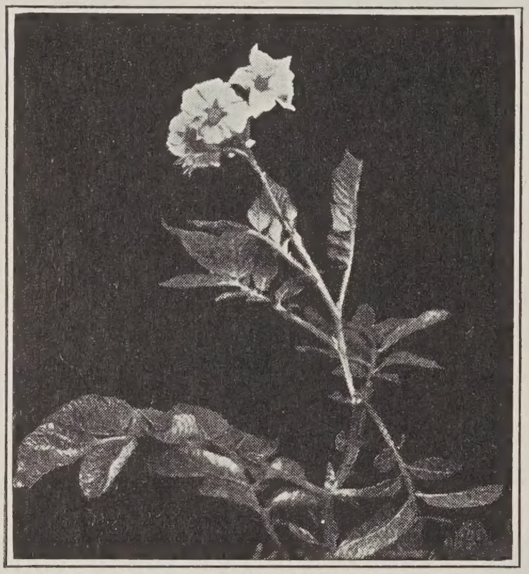
Courtesy I. A. Root Co., Medina, Ohio

FIG. 121. Each blossom in a head of clover is not unlike a pea blossom.

If you examine the blossoms of all these plants you can see that they are much alike. In some species the flower is small, in others it is large and showy, but most of them are rich in *nectar*, the sweet liquid changed into honey by the bee. The farmer sometimes places his beehives in his plum or peach orchard. He does this not so much to save the bees trouble as to get a better fruit crop for himself. You will read later how in visiting the flowers to obtain nectar and pollen the bees help to make good fruit.

The clovers and their relatives. Some of the plants in this family are sweet-scented too; and some form edible fruits. The clovers have blossoms that are small, but gathered so closely into a head that life is made easy for the bee that dips its sucking tube into the nectar bags.

Closely related to the clovers are the sweet pea with its showy blossom, the more humdrum, practical garden pea, and the beans. The last two put their energy into making large fruits instead of striking flowers. For the pea pod and the bean pod, to the botanist, are fruits. You may think of them as "vegetables" but you will learn later that they are as much fruits as are the apple and the pear.



© *P. Blakiston's Son & Co. Inc.*

Fig. 122. The potato plant has white or pale lavender flowers. The farmer gets his crop by planting pieces of potato instead of seeds.

Another member of the family is alfalfa (al-fal'fa) which means in Arabic the best fodder. In the south and west it is planted over many acres. Fresh or dry, it makes excellent food for cattle.

Other families that furnish food. The dicotyledon that is now raised, perhaps more than any other, to supply man with food is the potato. You may have read how it was introduced into Europe by the Spaniards and by Sir Walter Raleigh. The tomato and the pepper are close relatives. Strange to say, all these belong to the same family as the tobacco plant and the nightshades, one of which (a European form) provides us with the drug belladonna.

There are various families, many of whose members have been cultivated to supply us with "vegetables." The mustard family usually has small blossoms with four petals arranged in the form of a cross. Among the plants that it contains are the strong-tasting vegetables: the turnips, cabbage, cauliflower, brussels sprouts, and others. Of course, the onion and the leek do not belong here; if you have ever looked at their leaves, you know that they are plants with parallel-veined leaves, monocotyledons.

The goosefoot family includes two vegetables you would perhaps not associate, spinach and beets. The beet, of course, is far more important to man as a source of sugar than as a vegetable. Closely related to them is one of the commonest weeds, one that is always present in the vegetable garden, the pigweed or lamb's quarters.

The parsley family is another large, well known family. Most of its members have deeply cut compound leaves, like the table parsley, and tiny flowers grouped together in a flat-topped cluster. You have seen the lacy, wild carrot dotting the fields with white after the daisies are gone. Related to it is the carrot which is raised as a vegetable, the many parsnips, both wild and cultivated, and celery. Like the potato family it also has its "black sheep." The poison hemlock which, by the way, has no connection with the evergreen tree known as a hemlock, yields a powerful poison. The ancient Greeks used a drink brewed from it to put Socrates to death.

Plants that lend flavor to food. You have met some of the members of the large mint family: the mint, peppermint, spearmint, pennyroyal (used against mosquitoes), and sage. Some species of the mint family lack the strong odor, but you can usually recognize them by their square stems. The flowers are for the most part small and inconspicuous.

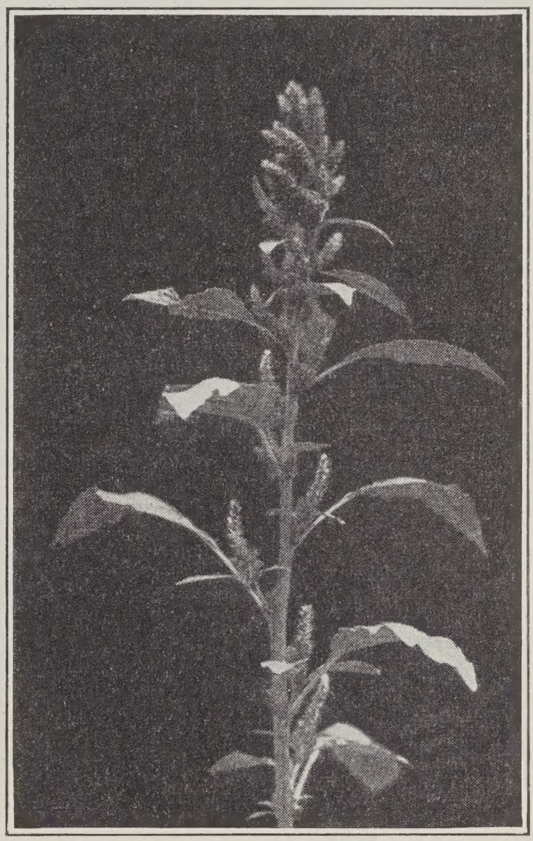
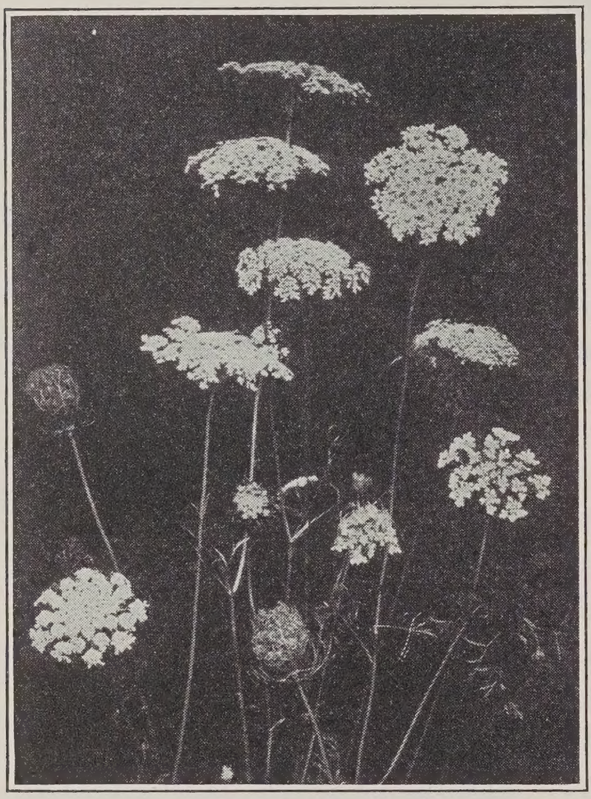


Photo by H. Schneider and J. Schwartz

FIG. 123. Pigweed. In some parts of the country it is cooked like spinach and used as food.

Plant families that have proved useful in various ways. When Columbus landed on the shores of South America he found the natives playing with a black ball that apparently moved and seemed alive. Several centuries later the substance of which the ball was made came into general use in Europe for "rubbing" out ink and pencil marks. That was the white man's first introduction to "rubber," as he soon learned to call it. Rubber comes as a milky liquid from the bark of numerous tropical trees belonging to many different families.

Far older than the rubber industry is the raising of the cotton plant. Its fruits when ripe burst open, disclosing a fluffy mass of white threads, which are attached to the seeds. Nowadays, the cotton gin is used to separate the seeds from the "cotton." The seeds themselves are squeezed until they give up their valuable cottonseed oil. What is left of them can be ground up to make food for cattle, or is sometimes spread on the ground as fertilizer.

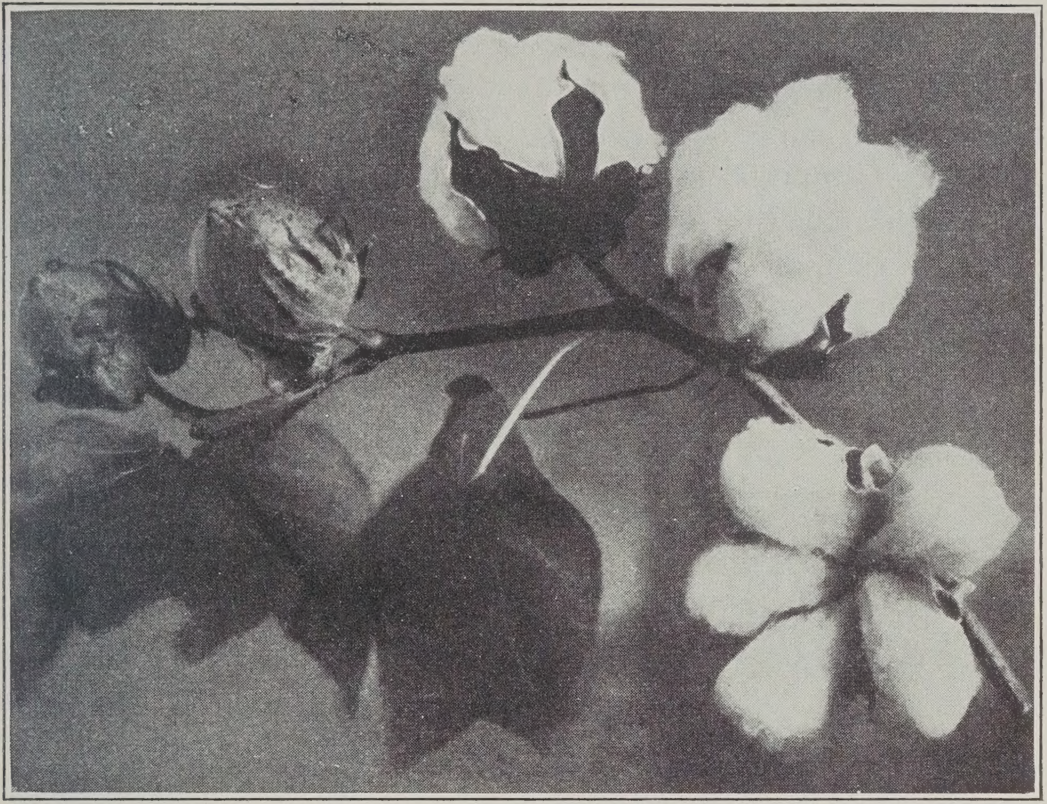


Courtesy Brooklyn Botanic Garden

FIG. 124. Wild Carrot. A prettier name is Queen Anne's lace.

Supplying us with fibers in a very different way is the flax plant. It has beautiful bright blue or white flowers. Although its leaves look somewhat like those of a grass, it is a dicotyledon. The threads which are later woven into linen come from the stems which must be "retted" or rotted in water. This loosens the threads. Its seeds are also used as a source of oil (linseed oil) and as cattle feed. There are plants of various families like hemp and jute whose stems or leaves supply tough fibers used in industry.

Another family of importance to man is the madder family. This includes among its useful members the coffee plant. Originally at home in Abyssinia, the coffee plant has been carried by man to many parts of the world where the climate is warm. There is a legend that it was discovered by an Arab goatherd whose atten-



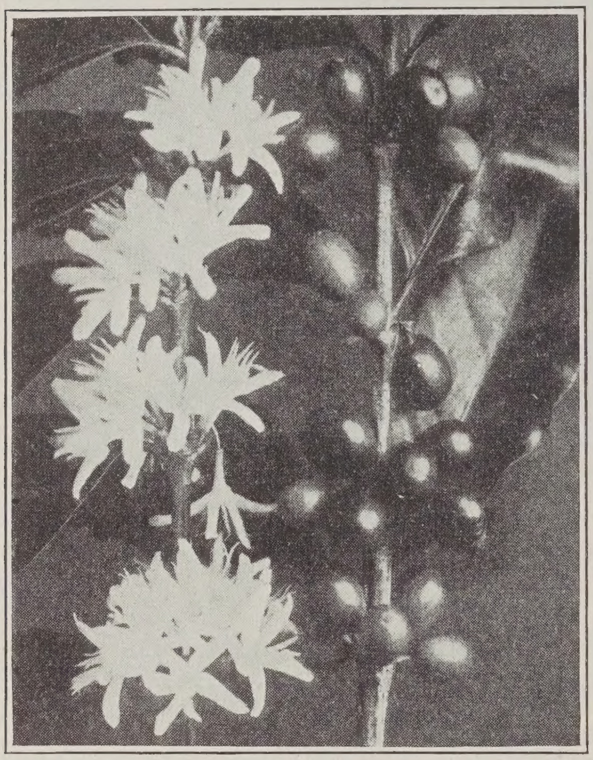
Courtesy United States Department of Agriculture

FIG. 125. The mass of cotton is so thick and fluffy that the seeds do not show in these fruits.

tion was attracted by the wild dancing of his goats. As he approached he saw them eating the berries of an unnamed shrub. He gathered these and from them the first coffee was brewed. Two other members of this family are the Cinchona (sin-koh′na) tree, whose bark yields the drug quinine, and the madder, whose roots have been used to dye cloth from the time of the early Egyptians.

A family whose flowers grow in bouquets. You have seen daisies in the pasture and dandelions in the lawn. What you have probably always called a daisy blossom is composed of many blossoms, and what you may have thought of as the white petals of the flower are not separate petals. The daisy is a very closely packed bouquet of two very different kinds of flowers. In the center is a yellow disc consisting of a large number of tiny flowers packed together so tightly that you need to look closely before you can distinguish them as separate flowers. Around them are the much larger white flowers, called "ray flowers" from their position around the center disc. Many plants in this family do not have the striking ray flowers. But these plants that bear many small flowers in one head so closely grouped that the head looks like a single flower belong to the family of *composites* (kompoz′its). Composite means being made up of distinct parts.

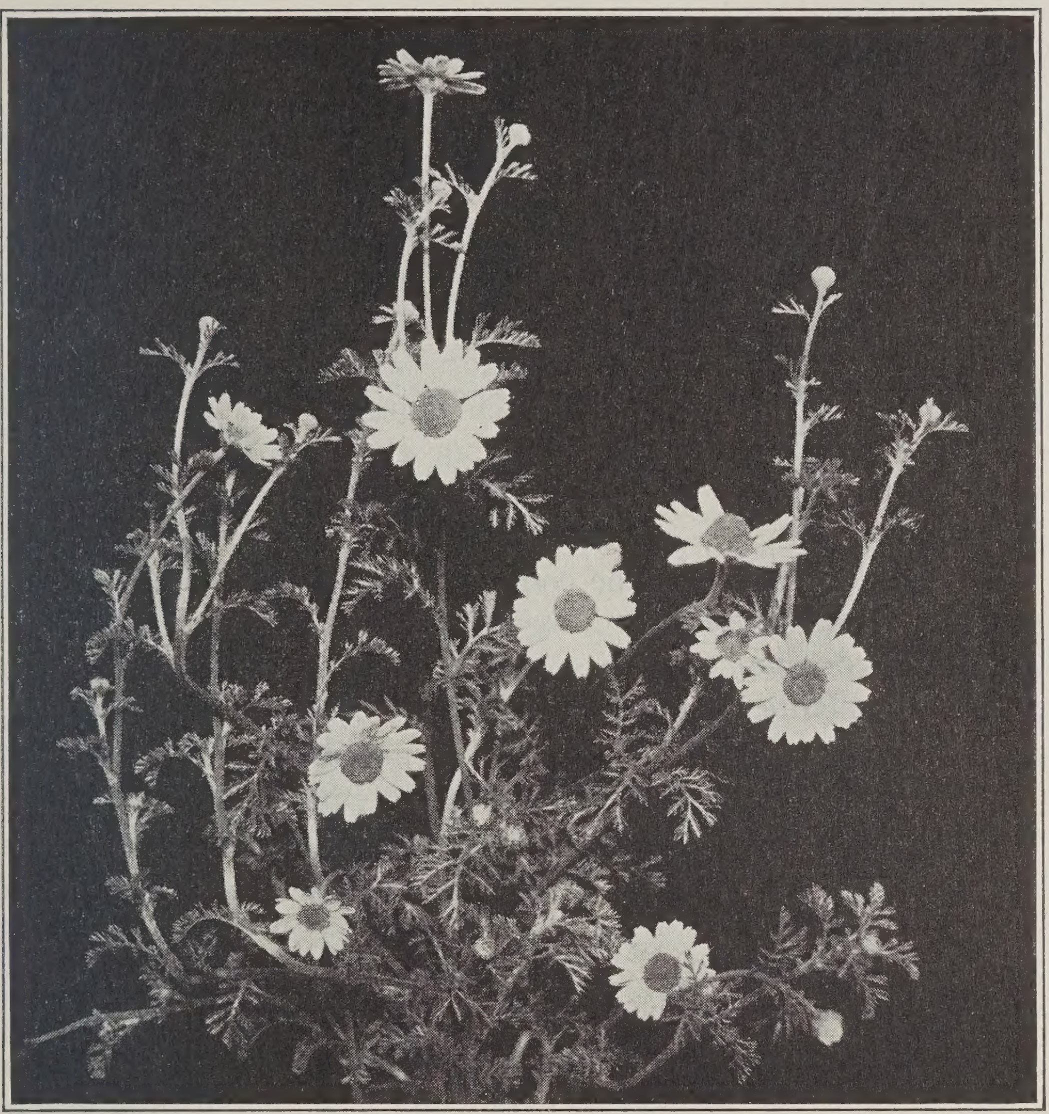
There is almost no end to the species of composites; some are as welcome to man as others are unwelcome. The dahlias and chrysanthemums adorn your gardens; the black-eyed Susan dots the fields with gold in the early summer; the large purple thistle grows untouched in the pasture; and the many goldenrods and asters add splashes of color to the hillsides, especially with the approach of autumn. Other composites content themselves with rubbish heaps and uncared-for city lots. Here you will find the burdock, which children often call "stickers," and the cocklebur with its vicious burs. Along the roadside grows the ragweed of hay-fever fame, and where the ground is damp, the wild lettuce. In the vegetable garden you will find the artichoke, oyster plant, lettuce, and chickory. These are all composites. It is by far the largest family among flowering plants.



Courtesy American Can Co.

Fig. 126. The white flowers and red berries of the coffee tree. Each berry contains two coffee "beans."

A long march in review. Many pages back you started on a journey in order to become acquainted with the many living things of this earth. In doing this your circle of acquaintances among organisms grew so rapidly that you would have been hopelessly confused had you not used some system for keeping them in separate groups. That is, you found it necessary to classify living things. The animals, of course, captured your attention first,



Courtesy Brooklyn Botanic Garden

FIG. 127. Camomile is a common composite. About how many ray flowers surround the central yellow disc?

especially the mammals, which are most closely related to you yourself. Then you marched hurriedly by the birds, the reptiles, the amphibia, and the fish. With the fish you left behind the animals which are built on the same plan as you. It was then you met the animals without backbones. You paused a long time here to get acquainted with man's insect friends and enemies and the other, less familiar, arthropods. From then on you saw mostly water forms; the strange, silent molluscs, the spiny echinoderms, the worms, some of which have left the water to burrow in the moist earth, the coelenterates which with their beautiful colors and unusual shapes remind one of flowers, and the sponges which have reduced living to its simplest terms.

At this point you stopped in your march. There were still many animals for you to see but your eyes were not strong enough. It was necessary for you to equip yourself with a microscope. Then suddenly a whole new world opened itself out to you, the world of Protozoa. A glimpse at these and you came to the end of your march through the animal kingdom.

You saw only very few of the almost one million different forms. Had you stopped to examine each living species for only one minute and had you marched on hour after hour, day and night, it would have taken you almost two years to review the animal kingdom.

Having marched from the complex animals right down to the simplest forms, it was necessary for you to retrace your steps. This time you shut out the animals from your sight and looked only at the plants. Bacteria and yeasts first held your attention, among invisible forms. Then, as you marched along, you were able to discard your microscope. You stepped back out of that other world of the invisible into the world which the human eye can see. On your return journey you searched the same waters that you had examined before. You saw seaweeds and water plants that never bloom. You moved on and found some of the simple plants living on the land. These plants were not at all like those you have always known, for they were not even green and many of them did not grow in soil. As your march progressed, you found more complex plants growing in the soil, first mosses and then the larger ferns.

Then you reached a place where you felt less strange. You were passing plants that looked like *plants*. First there were the evergreens that bear cones instead of flowers and then the real flowering plants. You marched by the grasses and the palms, and by the many plants you had seen before because their striking flowers had caught your eye. You marched under tall trees and trod on tiny herbs. At first glance they looked different but all of them had a root and stem and leaves and all bore blossoms and produced seeds. Having started with the simplest you had arrived at the most complex plants.

In the next chapters you will stand still, but you will live even more intimately with plants and animals until you have seen how they are constructed and how they do their work.

Pupil Activities

1. Having read the definition of an herb, a shrub, and a tree, can you name an example of each?

2. Look up and report on an industry that makes use of cone-bearing trees, such as papermaking or the making of varnishes.

3. Make an evergreen collection for the class museum. Mount and label a small branch and, if possible, a cone from each kind of evergreen that you can find.

4. Even in winter you can obtain examples of parallel and net-veined leaves at the florist shops. Compare them. You can skeletonize leaves by soaking them in dilute potassium hydroxide. Only the veins will be left.

5. Look up the bamboo, the sugar cane, the date, the cocoanut, or any of the cultivated grains in the Encyclopaedia Britannica or other reference books to obtain interesting facts about the way they are raised, gathered, and used in industries. Report.

6. Examine carefully some dicot flower, such as the sedum or sweet pea or violet. (You will find a description of the flower under plant reproduction in Part 2.) Can you identify the parts? Compare with a monocot blossom.

7. How large a collection of leaves of trees can you make? If you add descriptions of everything that you note about the tree your collection will be more interesting.

8. Instead of pressing the leaves you can make blueprints or spatter prints.

9. If you can draw well show the shape and general appearance of each of the common trees in your neighborhood.

10. When you know your trees a tree map of the streets of your city or town can be made.

11. Could you make a collection of different kinds of woods? Have you tools for smoothing and finishing to show the grains?

12. If the rose and apple are put into the same family, which part of the plant is evidently considered unimportant in classification? If you have seen pear or apple blossoms state how they compare with the rose blossom.

13. To make it possible for students to find the names of plants by themselves plant books have "keys." Ask your teacher to show you how to use one. Once you learn you will be able to "key down" specimens by yourself.

14. It is interesting to learn how to identify trees during the various seasons of the year. In the late spring, summer, and early autumn the leaves and new twigs are the best guides. In the winter, the buds, bark, and branching help. By using a good tree book you can find out the names of nearby trees and follow them throughout the year. If there are trees on the school grounds why not ask the shop teacher to help you make neat metal signs with the names?

15. You can learn the names of the common spring, summer, and autumn flowers by using a flower book. The pictures will help you if you cannot use the key.

16. *Summary.* Visit the vegetable market and make a list of the different plants seen. Perhaps several students could visit a florist shop and list the flowering plants there. In class, see how many of the plants listed you are able to classify into families. This will serve as a good review of the dicotyledons and monocotyledons. Now if you can sum up briefly what you read about cone-bearers, you will have summarized this chapter.

Good Books to Read

Adams, R. M., *The Family Garden.* Cornell Ext. Bull. No. 74.

Armstrong, M. N. and Thornbee, J. J., *Field Book of Western Wild Flowers.* Putnam.

Berry, J. W., *Western Forest Trees.* World Book.

Blakeslee, A. F. and Jarvis, C. D., *Trees in Winter, Their Study, Planting, Care and Identification.* Macmillan.

Chase, A., *First Book of Grasses.* Macmillan.

Clements, E. S., *Flowers of Coast and Sierra.* Wilson.

Clements, F. E. and E. S., *Rocky Mountain Flowers.* Wilson.

Clute, W. N., *The Common Names of Plants and Their Meaning.* The Author.

Curtis, C., *A Guide to the Trees.* Greenberg.

Daglish, E. F., *Marvels of Plant Life.* Butterworth (London).

Fabre, J. H., *Wonder Book of Plant Life.* Unwin (London).

Fry, W. W. and White, J. R., *Big Trees.* Stanford University.

Georgia, A. E., *Manual of Weeds.* Macmillan.

Griffith, M. S., *Gardening on Nothing a Year.* Hale.

Hanzlik, E. J., *Trees and Forests of the Western U. S.* Hanzlik, Portland, Ore.

Keeler, H. L., *Our Native Trees.* Scribner. *Our Northern Shrubs and How to Identify Them.* Scribner.

Longyear, B. O., *Trees and Shrubs of the Rocky Mountain Region.* Putnam.

Lounsberry, A., *Southern Wild Flowers and Trees.* Stokes.

Mathews, F. S., *Field Book of American Wild Flowers.* Putnam.

McKenny, M. and Seymour, E. L. D., *Your City Garden.* Appleton.

Muenscher, W. C., *Keys to Woody Plants and Shrubs.* The Author, Ithaca, N. Y.

Saunders, C. F., *Western Flower Guide.* Doubleday Doran.

School Nature League, *Catkin-bearing Trees. Evergreens. Insectivorous Plants. Opposite Branching Trees. Poisonous Plants. Some Berry-bearing Shrubs in Autumn.* The League, New York City.

Small, J. K., *Manual of the Southeastern Flora.* The Author, New York Botanical Garden.

Williams, S. H., *The Living World.* Macmillan.

TO THE STUDENT

Part 2 is written in Units and Problems instead of chapters. A unit, in simple language, is a single thing, a thing complete in itself. As used in a textbook, it means the explanation of a single fairly important idea, or the gathering together of information on *one* topic. Your first job is to read thoughtfully the title of the unit. You will sometimes be able to give some sort of answer to the unit question without further study. But to answer fully you will need to study the entire unit. To make this easier the unit is divided into parts, called problems. When you have answered each problem in turn, you will know the answer to the unit question.

In the same way, to make your study easier, the problem is divided into paragraphs. From each paragraph you get bits of information and very simple thoughts. If these are kept as separate facts or ideas they are not of much use to you. But if they are kept together in an orderly way they join together to make larger and larger ideas. The main thought in each paragraph is like a building block. When you have put these thoughts together you have answered the first problem in your unit — you have finished one story of your building. Soon you will answer the second problem, and add a story. In time you can answer your unit question — your building will be complete. You will be surprised to see how much easier it is to remember facts when you study in this way and how you begin to *understand* a great many new things which otherwise might seem very difficult to you.

If you do not make sure that you understand the main ideas in each paragraph it is just as though you were trying to build with blocks which crumble. It would be a waste of time to attempt to construct a building with such stones. It is as great a waste of time for you to try to understand a unit of information when there are important parts which you have not mastered.

Look back to the directions for study at the beginning of the book. Follow them now, for only in that way will you get full answers, first to the problem questions and finally to the unit questions.

PART 2

HOW PLANTS AND ANIMALS LIVE

OVERVIEW: THE BIOLOGIST IN THE LABORATORY

The biologist's workshop. A biologist sitting on a log in a tropical jungle once described the little clearing about him as his "laboratory." To this tiny open spot came his assistants with the plants and animals they had found in their searches: large, red-bodied ants, an insect-eating plant, a sleepy two-toed sloth, or a deadly snake. At one moment the biologist might be seen examining the complicated nest of an ant tribe; later, he might be engaged in studying the poison glands of the snake. The tiny shack near by held specimens and notebooks with day by day records of his work; it was headquarters. The clearing was his workshop, his laboratory.

Another biologist, using the word "laboratory," referred to the expertly equipped room in which he spent days bowed over a microscope. His workshop had sinks with faucets of different sizes; stone tables with vacuum and air pressure outlets and connections for gas and electricity; rows of shelves for bottles of dyes, acids, testing agents, and for reference books; cupboards with microscopes and other instruments. This workshop had everything the biologist's heart could desire. It was as different from the jungle clearing with its simple shack as two places could be.

Yet both men used the word "laboratory" in the same way. Both meant *the place in which I do my work.* It may be out of doors; more often, it is indoors. There the biologist can observe without interruption, and experiment freely, regulating the conditions of his experiments to suit his wishes.

Of course, a room in which one reads about a science like biology is not a laboratory. Nor are you a biologist when you read this book. The biologist does something different which marks him as a scientist: he studies real animals and plants, often by experimenting with them or by watching them in their daily lives, sometimes by examining their structures after they are dead. This was true of the man in the jungle and of his fellow biologist in the university building; even though one spent most of his time with live animals and plants and the other dealt chiefly with dead material. That is why a boy or girl who sets up a little place at home for scientific study speaks of the corner as "my laboratory." And if the laboratory is devoted to plant and animal study that boy or girl has built a "biologist's workshop."

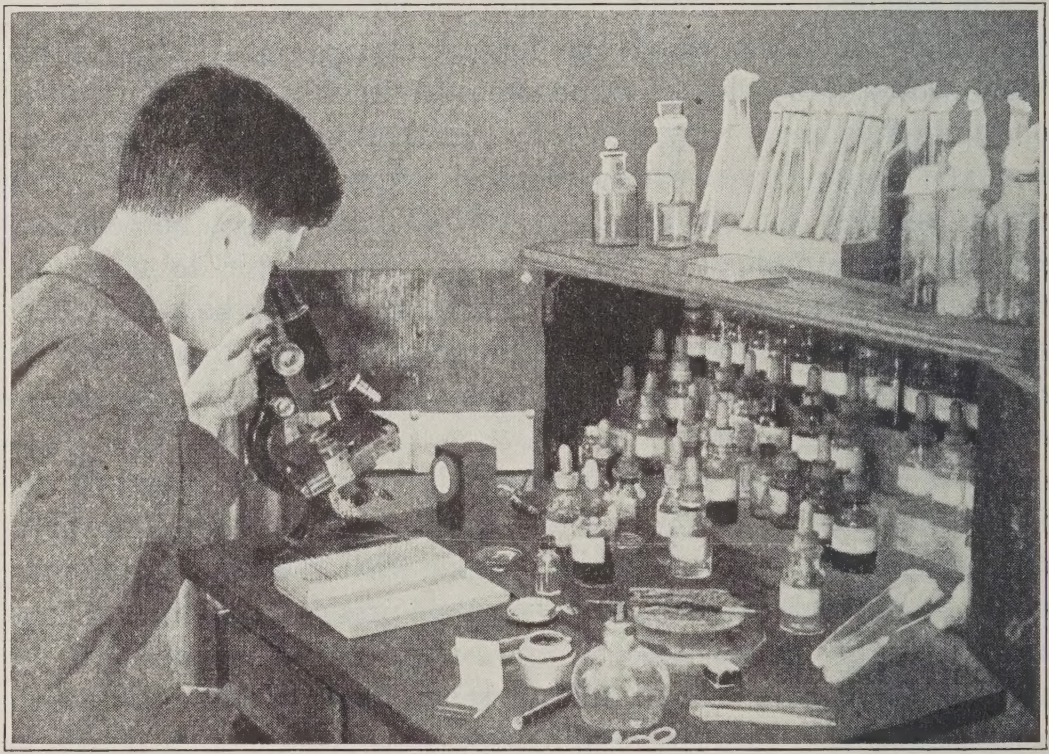


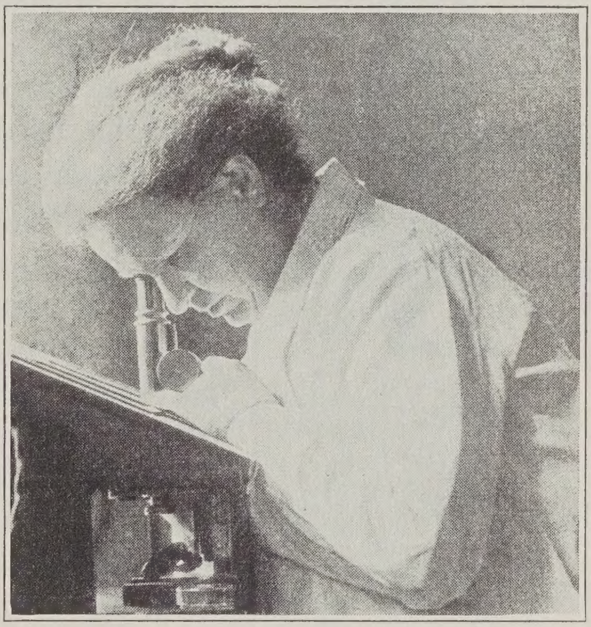
Photo by Alton Meister

FIG. 128. This is the home laboratory of a high school student. How many kinds of apparatus can you see?

Peeps into laboratories. Would you like to discover what puts the drive into those powerful muscles that hurl the football player to a touchdown? Do you know what makes your toes tingle when your foot goes to sleep? Do you know what makes some men develop into giants and some into dwarfs? Have you ever wondered how plants can grow in the desert in Arizona where, as this is written, no rain has fallen for two years?

Whatever the biological question you ask, there are, in this country, in France, in Australia, in China, somewhere on this earth, biologists interested in the same question, devoting themselves to its study in the hope of answering it by experiment or observation. If you could watch them at work and learn from them what they have discovered, many of your questions would be answered. Many, many problems, however, have not yet been solved; biologists, you would find, are still at work on them.

Of course, you might not understand what was going on in a biological laboratory until the work had been explained to you. You might find a famous biologist scribbling in a notebook and wonder what that had to do with dramatic discoveries and scientific achievement. And in another laboratory a young assistant, with his watch on the table before him, might be regularly placing little slides of glass into jar after jar of colorless and red and blue liquids. Only after you had remained with him for some time would you understand how that simple activity helped the experimenter to discover the cause of a disease like tuberculosis or gave you new information about the structure of living things.

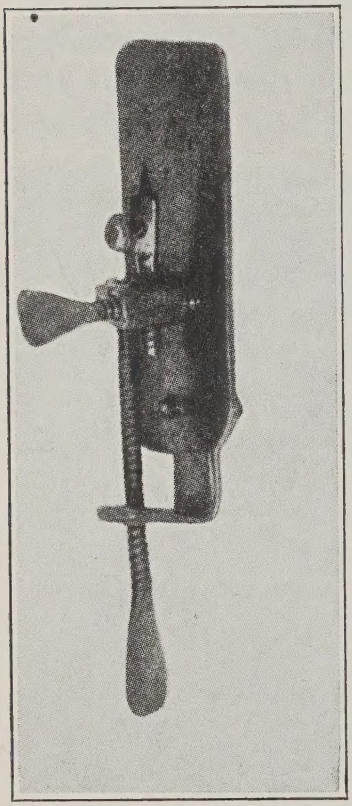


Acme

Fig. 129. Dr. Florence Rena Sabin, a great American scientist. She is working in her laboratory at the Rockefeller Institute for Medical Research.

The biologist sees the "invisible." Seeing the "invisible," that is, the things that cannot be seen with the naked eye, sounds like magic. But it is a magic with which you are all acquainted. Surely you have looked at human hair or newsprint or specks of dust through a magnifying glass and have been astonished at the enormous increase in size. That magnifying glass can also be used on living objects too small to be seen with the naked eye. Of course, there was a time when objects too small for the naked eye were really invisible. That was before magnifying glasses or the *microscope* (mike′ro-scope) had been developed. At that time men guessed that there were particles of matter too small to be seen, but no one imagined that there were living things so tiny. Men knew only the larger living things.

The man who first saw the microscopic creatures (those that can be seen with a microscope) was a Dutchman, Anton van Leeuwenhoek, whose hobby was making lenses. When he had ground and polished a small bead of glass until he was sure it would magnify well, he used it to examine all kinds of tiny objects to find out what they really looked like.



Courtesy Dr. A. T. Henrici

FIG. 130. One of Leeuwenhoek's many microscopes. A lens was fastened into the metal plate. The rest of the microscope is the object holder which can be screwed up or down and closer to the lens.

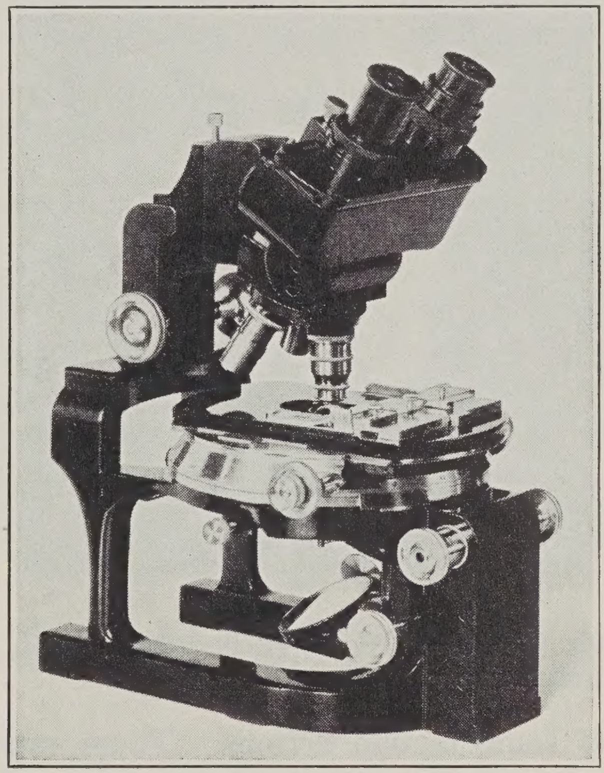
It was a great day for him and for biology when he decided to examine a drop of the rain water that had been standing in a barrel. Picture his amazement and delight when he found that the drop was a little world of wriggling, squirming creatures never before seen by man. When he reported his discovery, men in other countries used their lenses on similar drops of water. They, too, saw these hitherto invisible living things, studied them, filled notebooks with descriptions of their activities, and drew careful diagrams to show their structure.

The biologist improves his tools. As microscopes were improved, smaller and smaller living things were found and examined. Today, the best microscopes enable the biologist to study objects so tiny that if fifty thousand were laid end to end they would measure one inch long. But increase in magnifying power has not been the only advance. More important than that has been the increase in clearness of vision. When Leeuwenhoek looked, he saw objects somewhat blurred; today the magnified object looks sharper.

The modern microscope is an impressive instrument of shiny enamel and polished chromium but its lenses are really the most important parts. They are marvels of fine grinding, far, far better than any in the early microscopes. The modern instrument is unlike its ancestor in another way; it magnifies twice by means of two sets of lenses. That is why its correct name is *compound microscope*. This multiplies one magnification by the other. If the lens near the object magnifies fifty times and the lens near the eye ten times the total magnification is 500. That is how microscopes can magnify by as much as 4000 times.

The biologist studies the "mind." On a magic carpet and with a magic time machine you can visit the laboratory of the great Russian biologist, Ivan Pavlov, in the early years of the present century. Dr. Pavlov, who died recently, was studying the flow of saliva in dogs. Dogs were used as experimental animals because they were so easy to work with.

Pavlov wanted to find out what made saliva flow. But before he could experiment with a dog he had to perform a difficult operation. It was necessary to open a small hole in the dog's face through which the saliva could flow. Then it could flow out through a tube to which a jar was attached. The saliva was caught in the jar and the amount measured. Of course, it took weeks to train the dog to stand still in a harness so that the experiment could be performed successfully.

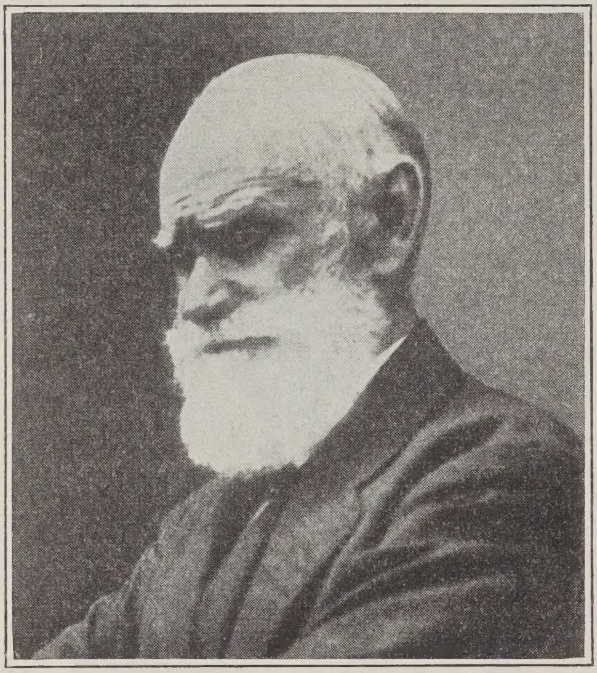


Courtesy Spencer Lens Co.

Fig. 131. The modern research microscope is far different from the simple instrument of Leeuwenhoek's day.

When food was shown the dog, the saliva began to flow, just as it does in human beings. But Pavlov did something else at the same time. When the food was put before the dog he rang a bell. This was continued for some time. Then, one day, Pavlov rang the bell without putting the food before the dog. Strange as it may seem, the saliva flowed from the dog's mouth just as it did when food was placed before the dog. Pavlov showed in this way that not only the normal cause, but an unusual cause, could lead to the flow of saliva.

This experiment was performed not once, but many times, and with many different dogs. In every case the sound of the bell could be made to start the flow of saliva. To make sure that this conclusion was correct, Pavlov tried other causes; in some cases he showed the food and touched the dog on its hind quarters; in other cases, he showed the food and also showed the dog a circle that had been drawn on paper. In every case, after the experiment had been repeated several times, the unusual cause produced a flow of saliva even when no food was put before the dog.



Courtesy Science Press

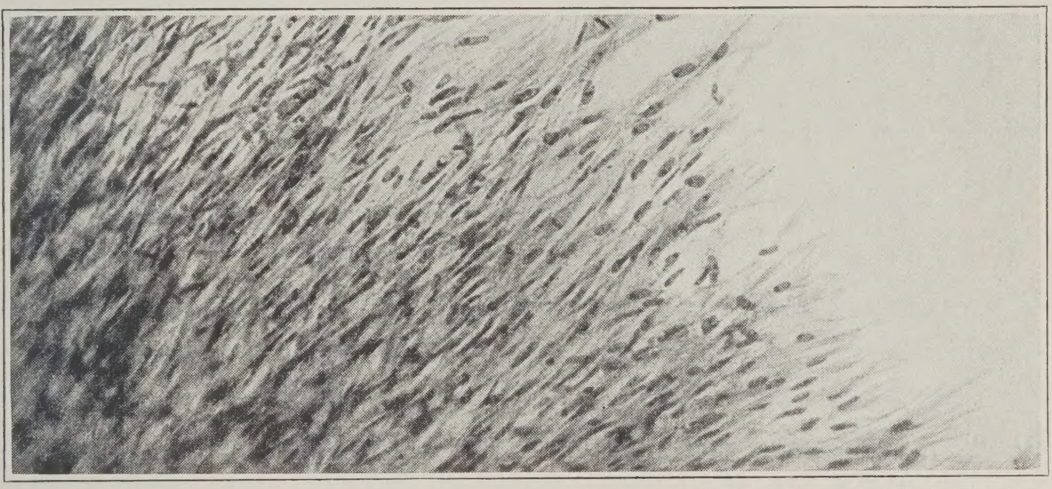
FIG. 132. Ivan Pavlov (1849–1936), a great Russian biologist.

By performing such experiments, Pavlov and other scientists have learned about the causes of some human actions. These experiments have even taught scientists a little about the way in which human beings learn something new.

But did you notice how carefully the stage was set for the experiment? Weeks spent in training the dog, years of study by the biologists to make possible the delicate operation, skillful construction of the cages and harness, patient watching for results, accurate measurement and recording of the facts day after day, the repetition of the experiment with many dogs — all this was necessary to make successful what may have seemed to you at first to have been a relatively simple job.

The biologist plays with life. Your next visit will be to a laboratory in New York City in the buildings of the Rockefeller Institute for Medical Research. Here the biologist in charge is

Dr. Alexis Carrel. For years he has been studying a little piece of animal matter that he keeps alive in a bottle. Other biologists had discovered a way of keeping it alive. Dr. Carrel began with a little piece of the heart of an unhatched chick. The little piece of heart muscle was cut out with as much care as the best surgeon displays in a difficult operation. Then it was placed in a specially prepared bottle with tubes permitting liquid to flow in and out. The tubes in turn were attached to a complicated apparatus which provided the tiny bit of heart with oxygen and food and removed all the waste materials. Many trials were needed before the liquid in the bottle contained just the right food and the proper amount of oxygen. Pages of records piled up.



Courtesy Drs. Carrel and Ebeling

FIG. 133. A bit of the chicken heart that has been growing in a bottle in Dr. Carrel's laboratory for more than twenty-five years. What is done when it grows too large?

The piece of heart remained alive. It grew. It grew so fast that within a day or two it was too large for the small bottle. It was necessary to remove part of it. Two days later the cutting had to be repeated. And it was repeated for weeks, for months, for years. The work is still going on. That bit of heart is still alive, more than twenty-five years after it was taken from the unborn chick, years after the chicken which it might have become would have died. In fact, Dr. Carrel declares that it is immortal in the sense that as long as it gets oxygen and food, waste materials are removed, and the new growth is cut down, that tiny piece of heart will continue to live in the bottle in the Rockefeller Institute.

So, in all the laboratories of the world, those you have visited in imagination and the many you cannot visit, the same procedure is followed: a question is asked; an experiment is planned; plants or animals are placed in conditions which will provide the answer; accurate observations are made and careful records are kept. This is how the biologist does his work.

UNIT I. WHAT HAVE ANIMALS AND PLANTS IN COMMON?

Problems

1. How Do Living and Lifeless Things Differ from One Another?
2. What Have Scientists Learned about the Protoplasm Common to Animals and Plants?

Problem 1. How Do Living and Lifeless Things Differ from One Another?

Where can you find an answer to the problem question? As you read this book you will gradually arrive at a simple understanding of the differences between living and lifeless things. Of course, even when you have finished the book your understanding will be incomplete because biologists themselves are unable to provide a complete answer. But some of the differences between living and lifeless things are not hard to understand; one of them is striking and can be stated simply. You will read of it in this problem. It became evident when scientists devoted themselves to a study of the structure of animals and plants.

What was learned about the structure of living things before the days of the microscope? Long before they had any clear idea of the nature of living things biologists *dissected* them (cut them up) to find out how they were built. Thus they learned that both plants and animals were made up of parts or structures which could be seen readily with the naked eye. The name given to these parts is *organ.*

This word must not be mistaken for the word *organism* which means a single individual or a single living thing. Every living thing is an organism whether it is complex and composed of many organs or is a tiny microscopic form.

Very early in their examination of organisms biologists noted that every organ has some work to do in the body. The word *function* (funk'shun) is used for that work. Thus one function of the hand is to hold objects. The three words, organism, organ, and function, are mentioned here because they will be used again and again throughout the book. The single difference between living and lifeless things referred to in the first paragraph has not yet been stated. It will become clear to you as you read the next few paragraphs.

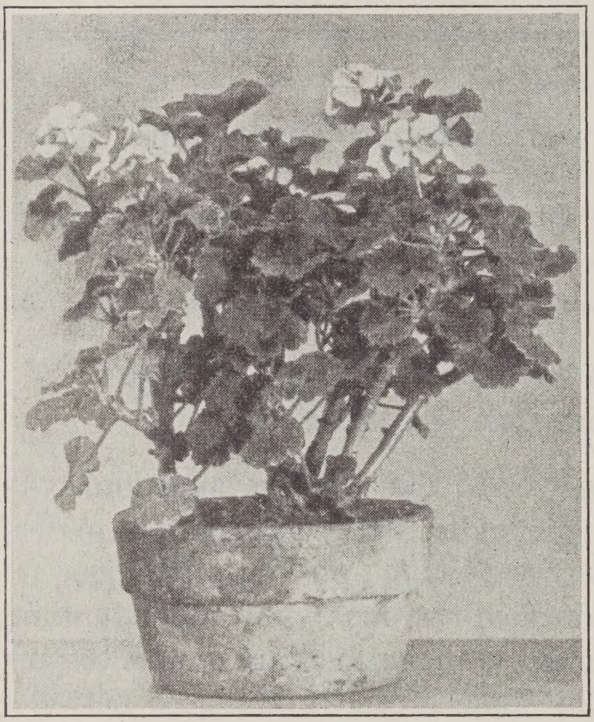


Photo by C. J. Sullivan

FIG. 134. Which of the organs of this geranium can you see? Which cannot be seen?

What are some of the organs of the more complex plants and animals? In Part 1 there were mentioned the names of some of the organs in a flowering plant. These were the root, stem, and leaf, each of which is an organ with one or several important functions. All three help to obtain food for the plant. The flower and seed were mentioned, too. They are organs which are chiefly concerned with producing more plants.

In a preceding paragraph the hand of man was spoken of as an organ. His arms and legs and ears are organs, too. But the word organ is more commonly used for internal parts as, for example, the heart, lungs, and stomach. These are organs which keep the body going. You could probably list several other internal organs, some of them with important functions.

Examination of complex animals shows that each important activity of the individual is usually performed by a set of organs instead of by one alone. For breathing, man needs more than lungs; he has nasal (nose) cavities and the windpipe to connect the lungs with the outside. The digestion of food is carried on by many organs; you know of the mouth, stomach, and intestines.

Similar groups of organs perform other general functions. And there is a name for such a group; it is *system.* Thus you speak of a respiratory (re-spyr′a-tory — breathing) system and of a digestive system. In the figure you will see some of the principal internal organs of man's body and can discover for yourself the arrangement of organs into systems.

Of what are organs composed? Several hundreds of years ago, at about the time the English were taking New Amsterdam (New York) away from the Dutch, scientists in Europe were trying to answer this problem of the make-up of organs. By using lenses attached to mirrors, Robert Hooke (1635–1703), an Englishman, examined a thin slice of cork from the bark of an oak tree. He discovered that it consisted of tiny empty boxes with thick walls and resembled a honeycomb. For this reason he called these boxes *cells.* At about the same time Anton van Leeuwenhoek (1632–1723) in Holland, Marcello Malpighi (1628–1694) in Italy, and many other scientists were trying out combinations of lenses and mirrors, and were examining everything that came to hand with these simple microscopes. Thus in looking at the skin, the blood, portions of insects, the leaves of plants, and every other part of animals and plants, they often saw cells. These cells were of various shapes and sizes. *Exercises 1, 2.*

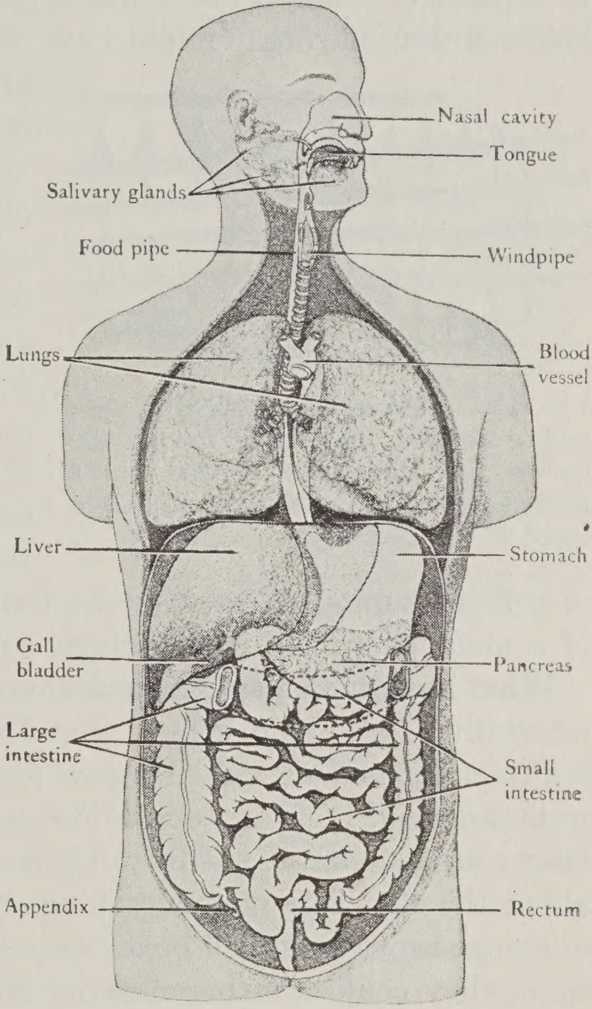


FIG. 135. You are looking into the body cavity from the front, but the heart has been removed. Find and list the organs of the digestive system. List all the organs the functions of which you do not know.

These early biologists of the seventeenth and eighteenth centuries were much interested in what they observed under the microscope; but they did not realize the importance of what they saw. They considered these little boxlike cells accidental structures in a plant or animal, much like a pattern or design in silk. They believed that one organ might have a design of round cells, another of oblong cells, and a third might lack cells altogether.

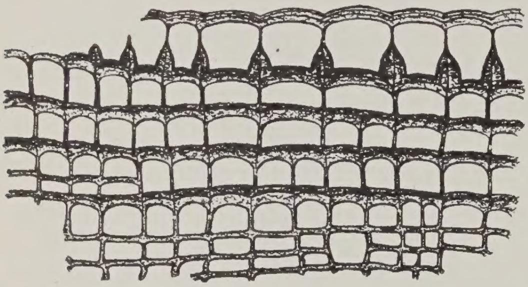


Fig. 136. A section cut through cork and examined under the microscope shows the structures which Hooke named "cells." Do these boxes seem to be filled or empty?

It was only later, just about one hundred years ago, that scientists began to realize that cells were much more than accidental structures. They realized that every plant and animal is completely made up of cells or of materials made by cells. They learned, in fact, that if a thing is not composed of cells it cannot be considered a living thing at all. Each organ of a plant or animal is, therefore, composed of cells.

What have biologists learned about the structure of cells? An interesting fact about cells is that Hooke named them but never really saw them at all! He saw many empty boxes with thick walls and called them cells. The name is still in use but it no longer means what it meant to Hooke. As biologists learned more about the structure of living things, they discovered that instead of being empty most cell boxes were full of some material. Sometimes they could see this material flowing. Very often the thick walls which Hooke had seen were lacking; the moving substance had the thinnest of walls around it or no wall at all. Gradually biologists became more impressed with the importance of this material and the unimportance of the walls.

Shortly after it had been pointed out that all living things are made of cells, biologists definitely gave up thinking of a cell as a box; rather, they thought of a cell as a little bit of active material. Of course, this material was given a name: *protoplasm,* which means first or most important substance. It is now known to be the living substance, present in every organism, and never found in lifeless objects. Hooke could not have seen protoplasm in the cork cells he examined because they were dead cells in which the protoplasm had disappeared, leaving only the walls. *Exercise 3.*

What is shown by a closer study of the cell? Before biologists named protoplasm they noticed that it is not the same throughout. Most of it is about as soft as mucilage, almost liquid in some cases. Somewhere near the center of the drop of protoplasm is a somewhat firmer, more concentrated part, usually like a ball in shape. This more concentrated kind of protoplasm is called *nucleoplasm* (nu'klee-o-plasm); and the ball of nucleoplasm is the *nucleus* (nu'klee-us). The softer protoplasm in which the nucleus lies goes by the special name of *cytoplasm* (sy'to-plasm). The part of the cell that contains the cytoplasm is known as the *cell body*. The outer surface of the cytoplasm always hardens somewhat, forming a *cell membrane.* Every cell, therefore, has a cell body; this is enclosed in a membrane and contains a nucleus.

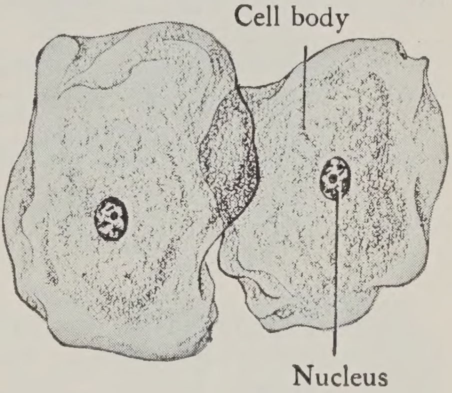


FIG. 137. These are cells which line your mouth cavity. How does Hooke's description of a cell fail to describe these cells?

In most plant cells the cytoplasm builds up a firm cell wall of lifeless material outside of the membrane. It usually consists of a tough transparent substance, *cellulose* (cell'you-lohss), or an even harder woody material. Most animal cells get along without a cell wall; even when it is present it is not made of cellulose.

In general, plant cells differ from animal cells in a second respect: there are usually one or more large bubbles of liquid lying in the cytoplasm of plant cells. These are called *vacuoles* (vak'you-ohls). The cell wall, the vacuoles, and other structures which you will hear of later, are often missing in animal cells and need not, therefore, be included in your idea of a "cell." A cell is really nothing more than a small mass of protoplasm slightly hardened at the surface, with a denser ball of protoplasm inside called the nucleus. *Exercises 4, 5, 6, 7.*

How do animal cells differ from one another? While all cells are fundamentally alike in that each is a small mass of cytoplasm with a nucleus, they vary considerably in size. Occasionally a cell is large enough to be seen with the naked eye; in fact, the yolk of the hen's egg is one cell enormously enlarged because of the food material it contains. But usually a cell is much smaller. It is difficult to appreciate just how small most cells are. It has been estimated that if you were to mark off two spots one inch apart on your skin about 400 cells would lie between the spots. In your whole body there are many billions of cells. You can see that most cells must be very small indeed.

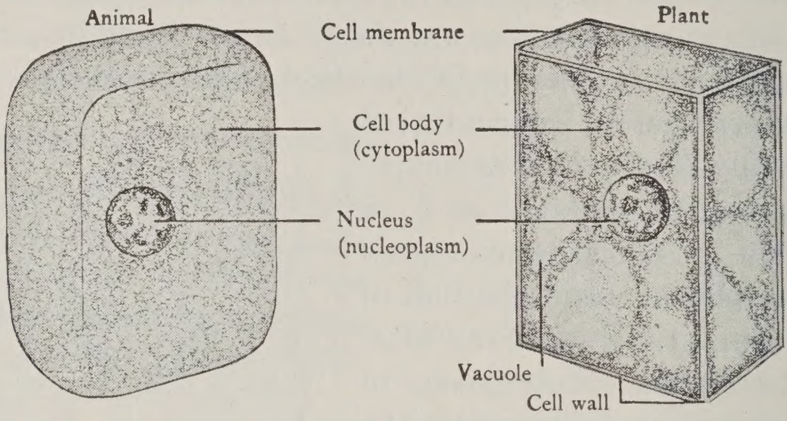


Fig. 138. All cells have three dimensions. In each picture there are two kinds of protoplasm shown. What are they?

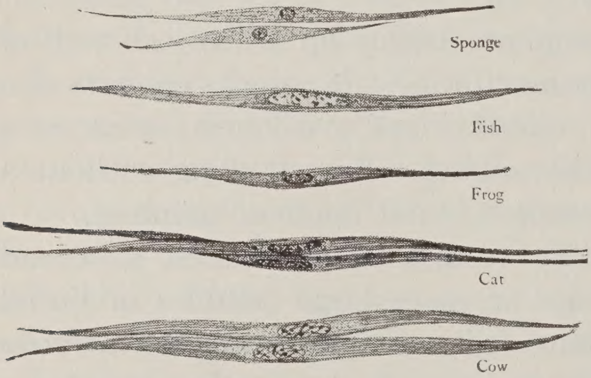


Fig. 139. What is striking about these muscle cells of animals as different as the sponge, fish, frog, cat, and cow?

Furthermore, cells are of many different shapes and differ considerably in their general appearance. That probably does not surprise you. No doubt you would expect the cells of an elephant to differ from those of the mouse. But the strange fact is that the cells of the elephant do *not* differ much from those of the mouse. And the cells of the mouse resemble those of man; those of man look like those of the horse, and so on.

The differently shaped cells are found right within one animal. The body of every organism is a collection of cells of many different shapes and sizes. And that collection is surprisingly like the cell collections of other animals. In other words, cells vary according to their position and according to the work they have to do rather than according to the animal in which they are found. *Exercise 8.*

How are the cells arranged in an organ? You saw that there are many different kinds of cells in the human body. If then you examine a large organ such as the arm, more closely, you will find that the surface is covered with skin cells, which protect; just below them are softer fat cells, which have the double function of acting as shock absorbers and of storing food. Where you feel the "flesh," lie muscle cells which can contract. On the very inside of the arm lie the bones, which have bone cells in them. The bone cells indirectly give support. These various cells are very different in appearance as well as in function. You can see that the different cells are not scattered hit or miss within an organ but are arranged in groups. The name *tissue* is given to such a group of cells all of which have the same function to perform and which are alike in structure.

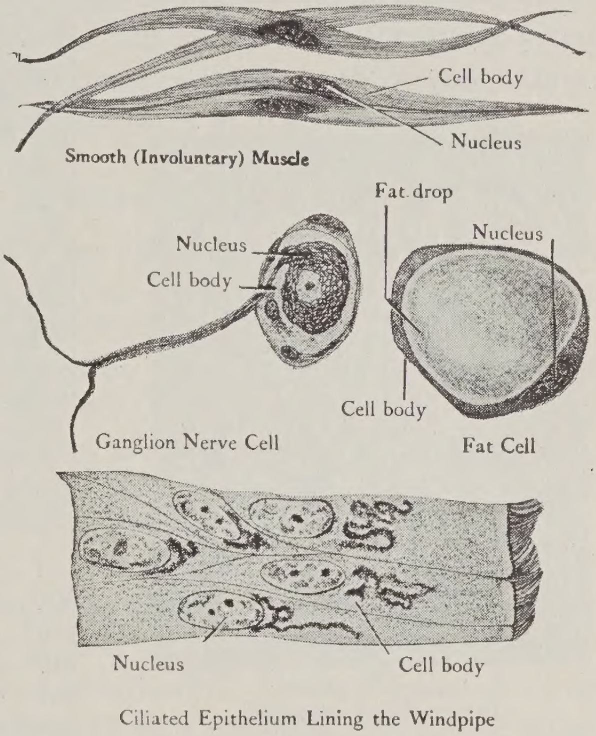


FIG. 140. These are some of the kinds of cells of which your body is composed. How are they all alike? How do they differ from one another?

In some cases the cells of a tissue make a special substance which comes to lie in the spaces among the cells. Sometimes such large amounts of it are made that after a while there may be more of this *intercellular* (between the cells) material than of the cells themselves. This is what happens in bone tissue. The bone cells lay down mineral matter around themselves and it is because of this mineral matter that bone tissue is able to give support to the other parts of the body. Another example of a tissue with large amounts of intercellular material is *cartilage* (kar′te-lej). The tough elastic material of the outer ear and of the tip of the nose is cartilage. It is found in many other parts of the body. *Exercise 9.*

You must therefore add something to your first idea of a tissue. You must think of a tissue as a group of similar cells, together with more or less intercellular material.

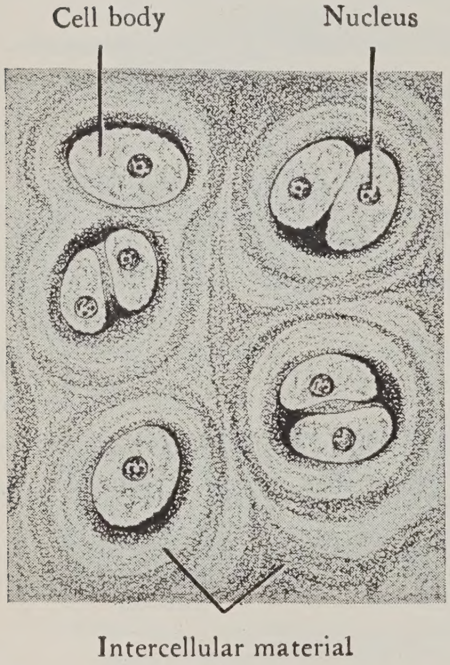


FIG. 141. Cartilage tissue. Compare the amounts of cellular and intercellular material.

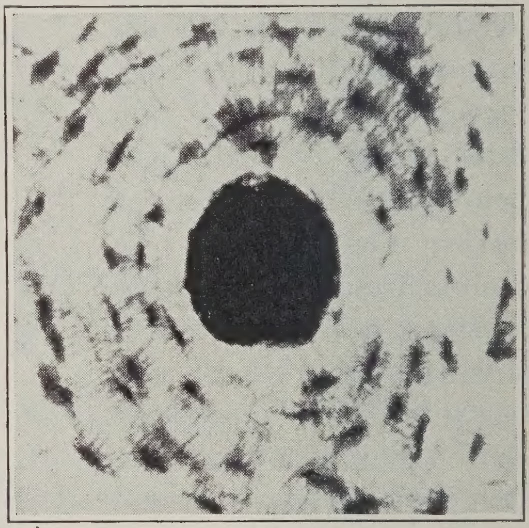

Courtesy N. S. Kline

FIG. 142. A photograph of a small part of a bone, taken through the microscope. The large dark spot is a tube through which blood vessels and nerves pass. The little irregular dark spots are the spaces in which bone cells used to be. What lifeless material did they build up about themselves?

Now if you look again at Figure 140, you will see different kinds of tissue cells; the bodies of all the more complex animals contain muscle tissue, nerve tissue, epithelial tissue, and so on. An organ does not always contain all the tissues found in the animal but it always consists of several tissues.

What is true of the animal is equally true of the plant. Its cells are also grouped together into tissues. Of course, plants do not have bone and muscle and nerve tissue. They have tissues of their own with which you are less familiar.

A challenge to biologists. You have read that it is cells, small masses of protoplasm, that make up all living things. Sometimes the organism is so small that it consists of no more than a single cell. More frequently the organism is made up of a very large number of cells. Then those cells are of different kinds and they are grouped together according to shape and function to make tissues.

Now the interesting thing is that while all living things are made of such similar cells there are a million different species of animals and plants. This substance protoplasm, or living matter, seems to have endless possibilities. It is for this reason that for many years scientists have been trying to learn more about protoplasm. You will read about some of their discoveries in the next problem.

Exercises

1. What does cork look like when highly magnified? Use the high power of the microscope* to examine a thin section of cork. Compare what you see with the drawing in the text.

2. What is the microscopic structure of onion skin? Cut an onion lengthwise. Separate some of the layers. With forceps peel off some of the thin skin from the inner side of one of the layers. Lay it flat and with a scalpel scrape it until it is as thin as you can make it. Mount a piece about $\frac{1}{4}''$ square in a drop of water on a slide. Lay a cover glass over it. Examine under the low power of the microscope. If there are too many black-rimmed circles (air bubbles) mount another piece. Draw what you see. Compare with the diagram of cork cells. How do these cells differ?

3. How does Ameba differ from other cells? Demonstration of living ameba under the microscope. Directions for culturing amebae are given under Activities for the Junior Biologist in Problem 2 of this unit. Do you see the protoplasm moving? Describe. How does the ameba cell differ from a cell of the onion skin?

4. What is the structure of onion skin cells? Prepare onion skin slides as in Exercise 2. This time study the cells carefully under both low and high powers. Draw only what you see. Permit a drop of red ink or a weak solution of iodine to run under the cover glass. What more do you see? Draw and label.

5. Copy (enlarged) one of the cork cells shown in the text. Fill in the parts which must have been there when this cell was alive. Label. Next to it draw and label an animal cell. How does the animal cell differ from the plant cell?

6. How may you see the cell membrane of a plant cell? Prepare slides of onion skin mounted in a drop of a weak salt solution. Observe under the low power of the microscope. What is happening to the protoplasm? Can you see the membrane now? Why were you unable to see the cell membrane before?

---

* Follow the directions given in Exercises 4 and 5 at the end of Unit X, Section 1.

7. How do the cells of the lining of your mouth (mucous membrane) differ from plant cells? Gently rub the inside of your cheek with a clean tongue depresser. Mount the material in a drop of water on a slide, cover, and examine under high power. Find a place on the slide where the cells are separated from one another. Stain with iodine solution, if cells are not clear. Draw and label several cells. What structures are present in the plant cells that are not in this cell?

8. How did striated (striped) muscle get its name? To see the striations in muscle cells, tease apart some fresh beef muscle and mount several small strands in a drop of water. The striations may be seen more clearly if the strands are not too thin. Examine under high power. You will not be able to see individual muscle cells because the boundaries of these cells are not defined clearly.

9. Is a bone a tissue or a collection of tissues? Obtain a beef or lamb leg bone sawed lengthwise through the middle. Scrape it clean of meat. Use a strong dissecting needle to detect the covering on the shaft (long part) of the bone. Describe it. What might be the function of this covering? Feel the substance that covers the head of the bone. Is it hard or soft? Rough or smooth? This is cartilage. Prick the inside of the head with the needle. What substance do you find? What color is it? What gives it this color? This is known as red marrow. Prick the material outside the marrow; this is true bone substance. Feel the substance in the inside of the shaft. This is yellow marrow. How does it differ from red marrow? Examine some of the red marrow under the microscope. Name all the substances you have found. Is the bone a single tissue or a collection of tissues? Of course, you cannot see the bone cells with the unaided eye. Your teacher will give you a prepared slide of a cross section of the bone. Examine this under high power. Notice the long dark spots with many fine projections. They are arranged in concentric circles (circle within circle) around a large circular opening. In life, blood vessels and nerves run through these circular openings. Each long spot with radiating projections is a space in which a bone cell used to lie. The protoplasm has disappeared.

Problems for Classroom Discussion

1. Turn to the chapters on insects and on fish in Part 1. Examine the figures. Name some of the organs of each animal. What is the function of each organ?

2. If you were the teacher preparing a test on the second paragraph in this problem, what questions would you ask the class?

3. If you can see the nucleus in the center of a cell, what must be one characteristic of the cytoplasm and the cell wall?

4. Can you explain how your idea of a cell is quite different from Hooke's?

5. When you have finished the paragraph "What is shown by a closer study of the cell," summarize it by stating each important idea in the paragraph.

6. Can you describe (or draw) the nerve, fat, or epithelium tissue that you would expect to find in a dog or in a rat?

7. Some tissues feel hard to the touch, some soft. In which would you expect to find the larger amount of intercellular material? Explain.

8. *Summary.* Look back to the problem question. Can you answer in one very short sentence? This problem introduced so many important thoughts and new words that you must summarize it carefully. Starting with the second paragraph, list its title. *In your own words* and very briefly, state every important idea in that paragraph. Do the same with the next paragraph, and so on to the end of the problem.

Activities for the Junior Biologist

1. You can easily learn to prepare slides for your own study. Try various ways of putting on the cover glass so that bubbles will not form. Which do you find is the best way? Consult books or ask your teacher for further help. In time you will probably want to learn how to make microscope slides which are permanent. This is difficult and takes patience.

2. Can you think of some way of making a model of a cell which will give your classmates a good idea of how a cell really looks? (Do not forget that protoplasm is transparent.)

3. A group can plan to make models of different kinds of cells. This makes an interesting demonstration in the classroom.

4. By using a magnifying glass and a scalpel, try to learn something about plant tissues. Can you distinguish different ones in a stem and in a leaf? Are they like animal tissues? If you have a microscope you may be able to tease some of the tissues farther apart and see some of the cells.

5. De Kruif's *Microbe Hunters* and many other books will give you an interesting account of Leeuwenhoek's life and work. Prepare a short talk on this.

6. If you have a camera and are interested in photography, you can develop the fascinating hobby of microphotography. Ask the class secretary to write to Eastman Kodak Co., Rochester, N. Y., for a booklet. If there is a Camera club in your school, consult with some of its members.

7. You might wish to preserve and mount the skeleton of a small animal for a class museum. Ask your teacher for a reference that will explain how to do this or consult a Turtox leaflet.

8. How much may cells vary in size? Mount some mucous membrane cells. Add a drop of water containing a little dilute yeast mixture. Examine under the high power. What is the difference in size? There are cells which are larger than mucous membrane cells and others smaller than yeast.

Problem 2. What Have Scientists Learned about the Protoplasm Common to Animals and Plants?

Why does the biologist turn to the chemist for help? The same object or substance may often be studied in different ways and for different reasons by scientists. A piece of wood may be examined by a biologist who is interested in its grain; another scientist may wish to find out of what substances the wood is made. He may burn it to find out what will be left or use acids to discover what changes they will make in the wood. The second scientist is interested in the composition or make-up of the wood and in the changes which wood may make in other substances or which they may make in it. Such a scientist is called a *chemist*.

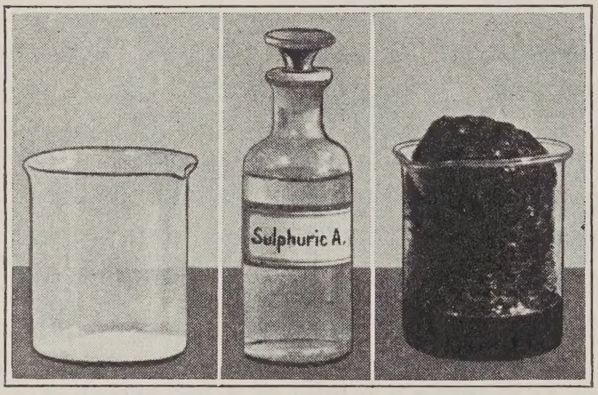


Photo by C. J. Sullivan

FIG. 143. When the chemist added sulphuric acid (H_2SO_4) to the sugar, the dark mass of carbon was produced. How does this startling change in the sugar help the chemist to find out of what sugar is made?

The biologist turns to the chemist, therefore, whenever he wishes to learn about the composition of some material. When it was discovered that living things were made up of protoplasm, chemists went to work to find out of what protoplasm itself was composed. Of course biologists soon borrowed the methods of the chemist so that they could do this work themselves.

What has the chemist taught us about our world? In trying to find out the composition of the various things about them, chemists found this startling fact. They could break down most things and find out the simpler substances of which they were composed. But every once in a while they would find a substance which refused to be broken down. For example, by passing an electric current through water in which a little acid had been placed they were able to break down the water into two substances, quite different from one another, known as *oxygen* and *hydrogen*. But when they attempted to learn of what oxygen and hydrogen were made they discovered that these substances cannot be broken down into anything else. *Carbon*, *iron*, *sulphur*, *nitrogen*, and some others were just as stubborn; in every chemical experiment they remained as substances which could not be broken down any further.

To such substances the chemist gave the name *elements*. After all the years of experimentation the chemist has found only about 92 elements. Six of the very common ones were named above. *Exercise 1.*

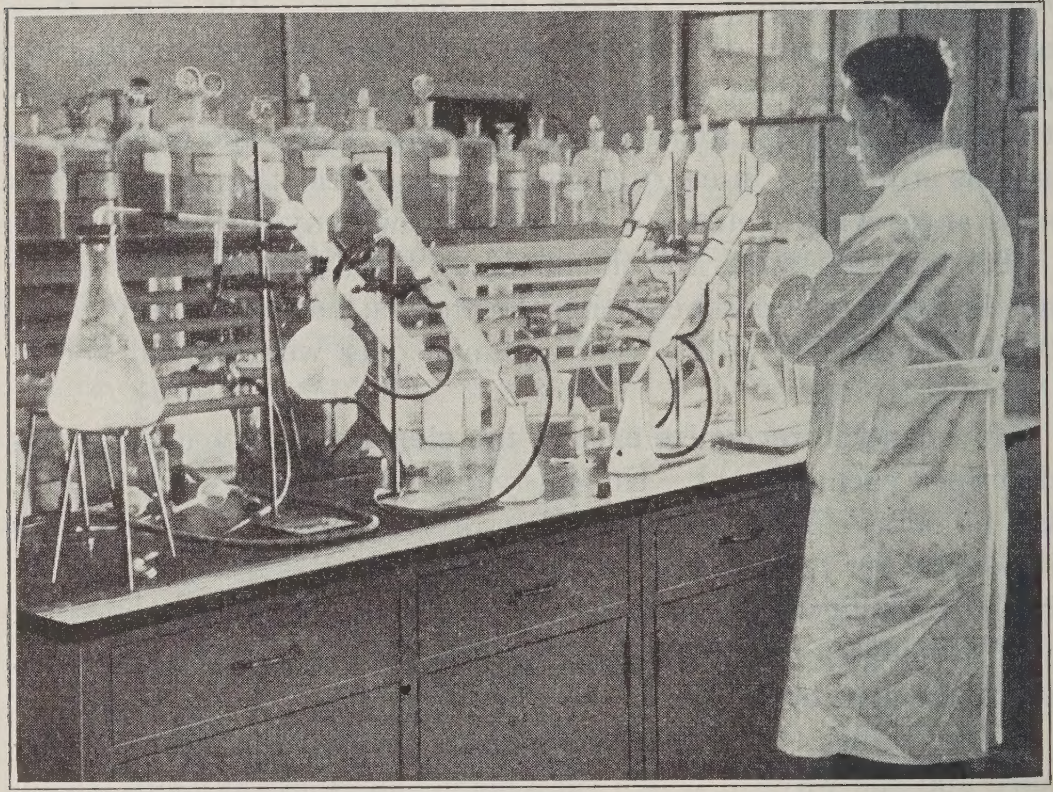
How can you recognize each of the elements? The chemist has described each element. He can tell you that oxygen is colorless, has no odor, cannot be tasted when dissolved in water, and makes it possible for things to burn. Nitrogen, which is also a gas found in the air, differs from oxygen in that it does not support burning. If a burning candle is put into a bottle containing pure nitrogen, the flame goes out at once.

These things that substances can and cannot do, their appearance and the ways in which they affect our senses of sight, taste, and smell are called their *properties*. Thus the properties of iron include its ability to carry an electric current, its hardness, and the fact that it melts at a high temperature; lead, another element, differs from iron in that it melts at a comparatively low temperature and is softer. The properties of the two elements are not the same.

By performing countless experiments, chemists have been able to list the properties of almost all the elements, so that it is easy now to distinguish one from another. *Exercise 2.*

Combinations of elements. Since there are only about 92 different elements, all of the thousands upon thousands of different things in the world must be various combinations of these elements. This may seem startling at first, but when you consider that all the words which fill the large dictionary in the school library are different combinations of the 26 letters of the alphabet you will appreciate how many combinations might be formed out of 92 elements!

Now when elements combine the chemist calls the substance that is formed a chemical *compound.* But the compound is not a simple combination in the same sense that a word is a combination of letters. In the word you can recognize each letter, for it does not change when it is combined with other letters. But when one element is combined with another in a compound, each element loses its own properties and is no longer recognizable as an element. That is another way of saying that the compound which results is something altogether new. It has properties quite different from the properties of the elements of which it is made. For example, you read before that water can be broken up into hydrogen and oxygen. That is, water is a compound consisting of these two elements. Hydrogen and oxygen are gases; water is a liquid.



Courtesy National Dairy Council

FIG. 144. The chemist works with tubes and bottles, acids and other substances. Which of the things in this laboratory can you name?

Hydrogen burns and oxygen makes burning possible; water does neither. No one could possibly have guessed by looking at it that water is a compound of oxygen and hydrogen. *Exercise 3.*

Chemists discovered a long time ago that single elements are not the only substances that can unite chemically to form a new substance with new properties. Compounds also can combine with one another to form larger compounds; or elements can combine with compounds. But not all elements or all compounds will unite. Some elements and compounds are active uniters; others are not. The gas oxygen is one of the most active elements; the gas neon which is used in the brilliant red lights for store advertising is an inactive gas. It is extremely difficult to get it to unite with any element or compound.

What is the result when you put together substances which refuse to combine? You may know that hydrogen and oxygen are such active uniters that when they are brought together and heated a violent explosion results, and water forms. But you can put hydrogen and oxygen together into a jar without heating, shake it well, and there will be no explosion and no water will appear. Each gas keeps its original properties and no new substance appears. In this case, evidently, no compound is formed. The chemist calls such a group of substances just what you would call it in everyday speech, a *mixture*. *Exercises 4, 5, 6.*

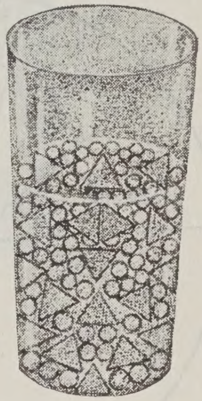


FIG. 145. Particles of sugar are shown as triangles, particles of water as circles. Does sugar water seem to be a compound or a mixture? Explain.

What elements are found in living matter? Scientists have long been studying protoplasm by chemical methods in order to find out of what it is made. Unfortunately, these methods make it necessary to kill the protoplasm so that our information is really about dead protoplasm, which is not living material at all. But such methods are accurate enough when one is interested in finding out the elements which make up protoplasm.

In breaking down the protoplasm of many kinds of cells chemists found nine elements present in every case. They are elements which are also common in the earth, air, and water about us. Some of them have been mentioned already. These elements are:

oxygen (O), nitrogen (N), hydrogen (H), carbon (C) (a black solid), sulphur (S), phosphorus (P), iron (Fe), potassium (K), and magnesium (Mg). *Exercise 7.*

These are not the only elements that have been found in the protoplasm of living things. There are many others, usually found in very small amounts. But the elements listed above are found in all living things; without them there can be no living substance.

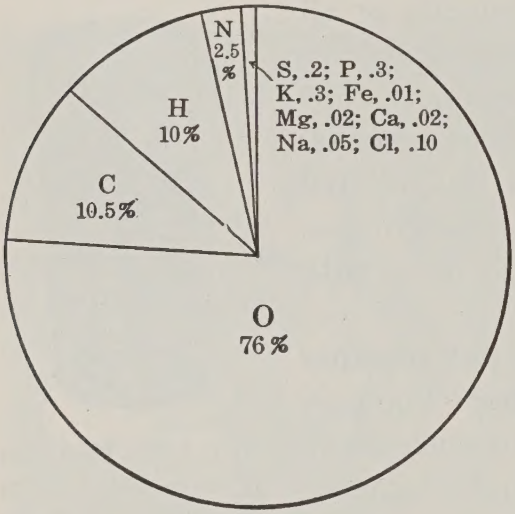


FIG. 146. The twelve most common elements found in plant and animal protoplasm with their percentages by weight. The calcium (Ca), sodium (Na), and chlorine (Cl) are not present in all living things. (*Plunkett.*)

In what form do these elements appear in living matter? Tests based on the properties of the elements show that the nine elements always present do not appear in living matter as uncombined elements. Protoplasm is not, therefore, just a mixture of these elements. It is a mixture of various compounds.

The commonest of all the compounds in protoplasm is water (H_2O). It forms a large part of every cell. Other common compounds are minerals like table salt, sodium chloride ($NaCl$). They, too, are present in every bit of protoplasm which is broken down. Like water they are common outside of living things, too. But there are other compounds never found in the world of lifeless things.

Many of these compounds are very complex. Their elements are combined with one another in such a way that it is difficult for man to make them unite in the laboratory even when he knows the composition of the compound. There are many compounds in protoplasm but those most commonly present besides water and minerals are proteins and fats. Sugars and starches are found in the cell, but as stored material.

Sugars and starches in the living cell. Not only is it true that sugars and starches are found in the living cell but the living cell is the only source of these compounds. They appear on your table; you find them on the pantry shelf, where they seem not to have the

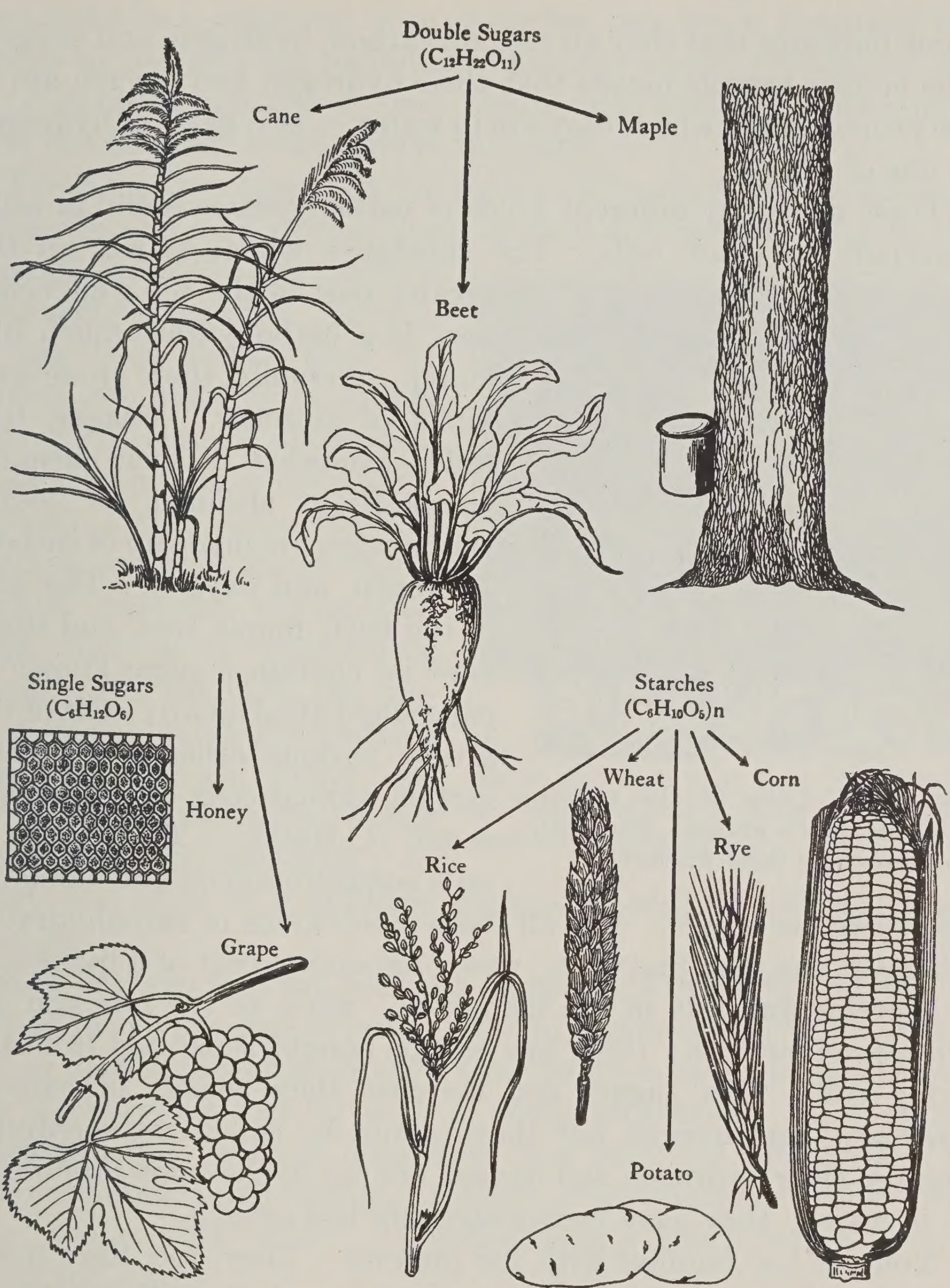

Double Sugars
($C_{12}H_{22}O_{11}$)
Cane
Maple
Beet
Single Sugars
($C_6H_{12}O_6$)
Honey
Grape
Starches
($C_6H_{10}O_5$)n
Wheat
Corn
Rye
Rice
Potato

Fig. 147. Did you believe that sugars and starches were made in factories? They are only taken out of the plant and refined and packed in the factory.

remotest connection with living things. But it is only because man has learned to extract them from living cells in such large quantities that they are sold everywhere over the counter.

Although sugar does not seem to you much like cornstarch or laundry starch, the chemist finds them so similar that he groups sugars and starches together and calls them *carbohydrates*. The name indicates that they all contain carbon, hydrogen, and oxygen. The ending *hydrate* means that their hydrogen and oxygen are in the proportion in which they are in water — two parts of hydrogen to one of oxygen.

There are many different kinds of carbohydrates found in cells, especially in plant cells. The substance which makes up the greater part of the cell wall, cellulose, is a carbohydrate much like starch. Actually, there are several kinds of starches. Sugars, too, differ somewhat in their chemical composition, although of course they always are made up of carbon, hydrogen, and oxygen. The cells of the beet, maple tree, and sugar cane all contain a sugar known as cane sugar ($C_{12}H_{22}O_{11}$); cells of the grape, various other plants, and certain animal cells contain grape sugar ($C_6H_{12}O_6$). Then there is milk sugar (found only in animals), and there are others. But all these many kinds of carbohydrates, wherever you may find them, were originally a part of a living cell.

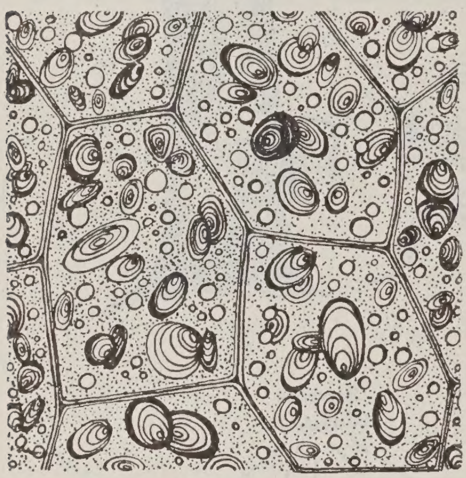


FIG. 148. Cells of the potato showing starch grains. How can you recognize these grains?

Proteins and fats in the living cell. Some of the fats you are quite familiar with; they, too, can be bought separated from the living cell. Like sugars and starches they consist of carbon, hydrogen, and oxygen but they cannot be called carbohydrates because their hydrogen and oxygen are not in the same proportion as in water; they have proportionately less oxygen.

You are less familiar with the proteins. They, too, have never been found outside of living things or the products of living things. They are an important part of the protoplasm, for protoplasm must always contain them. Of course, there are many different proteins. Proteins are far more complex than the carbohydrates or fats, always containing nitrogen (N), sulphur (S), and often small amounts of other elements besides the everpresent C, H, and O.

Does protoplasm always have the same composition? You have learned of some of the compounds that make up living matter: water and mineral compounds, sugars, starches, fats, and proteins.

And since each keeps its own properties you know that they are simply mixed, and not combined. In other words, protoplasm is a very complex mixture of both simple and complex compounds. And this mixture is not always the same.

These many compounds are mixed differently and in different proportions in each species (kind) of plant and animal. That is, the protoplasm of the dog's cells is not exactly like yours. In fact, it has been found that the protoplasm not only of species but of individuals differs too. Your protoplasm is not identical with mine. Even the protoplasm of one tissue has a slightly different composition from that of a neighboring tissue. For example, the protoplasm of a nerve cell contains much phosphorus; blood cells contain unusually large amounts of iron, and so on. In every case there is a different mixture of slightly different compounds.

Courtesy N. Y. Botanical Garden

FIG. 149. The protoplasm of this water lily, like your own protoplasm, is made up of water, proteins, minerals, starches, and sugars.

How can you find the common compounds in living matter? It is easy for you to detect water, mineral compounds, starch, sugar, fat, or protein in living things. You can do so because the chemist has discovered a test for each of these substances. After much experimenting, chemists discovered that starch in the presence of iodine solution turns blue and that no other substance behaves in this manner with iodine. Therefore iodine solution is a testing agent for starch.

In the same way simple tests have been discovered for sugar, for protein, for fats, for mineral matter, and for water. Finding these tests was a difficult task; but applying them is an easy matter. It would be impossible for you to try the test on a single cell because of its very small size. But if you take a mass of cells from a plant or animal and follow the directions that the chemist gives, you can convince yourself of the presence of these simple compounds in living matter. *Exercises 8, 9, 10, 11, 12, 13, 14.*

What has the biologist added to the discoveries of the chemist? The jellylike protoplasm, though made up of very ordinary elements, does not behave in an ordinary way at all. As you know, it does many things that lifeless material does not do. If you have studied ameba or slime molds under the microscope you saw the blob of protoplasm stream or move. Physical and chemical changes go on within it which enable it to do this; it has *contractility* (can contract). When given stuff called "food," protoplasm takes it in and makes more protoplasm out of it; this is *growth.* In time, the one cell will make another cell like itself; it has the power of *reproduction.* And there are other respects in which it behaves very differently from lifeless material. You have seen a living plant, or a living animal, do many things. Whatever it does it is able to do because of the special properties of its protoplasm. Therefore you will be learning a great deal more about the behavior of protoplasm as you study the plants and animals about you. *Exercise 15.*

Exercises

1. Of what is water composed? To answer this question you must pass an electric current through water in a special apparatus. Measure the amount of gas that is formed in each tube of the electrolysis apparatus. The gas formed in smaller amount is oxygen; the other, hydrogen. In what proportion are the two gases combined to form water? Do the gases differ in color or odor? Collect the gas from each tube separately in a small test tube. Allow no air to enter these test tubes. Test each gas with a lighted splint. Describe what happens. Write down all the interesting facts you have discovered.

2. What is one striking property of oxygen? Prepare oxygen by heating a mixture of three parts of potassium chlorate and one part of manganese dioxide. (Consult a chemistry or general science text.) Collect several small bottles of the gas by displacing water. Into one bottle thrust a burning splint. Burn some sulphur in a deflagrating spoon and put it into a bottle of oxygen. Into a third bottle put a strip of burning magnesium. Thrust a glowing stick of charcoal into a fourth. Describe carefully what you saw in each case. Why does each substance stop burning after a short time?

3. Can you devise an experiment in which you get two elements to combine to make a compound? (*Hint.* Charcoal is almost pure carbon. Carbon dioxide is a compound consisting of carbon and oxygen. You can detect the presence of carbon dioxide because it turns clear limewater milky.) Can you put these same elements together without having them combine? How?

4. Can you find out by experiment whether the diagram of sugar water is correct? Verify by heating some strong sugar water in an evaporating dish. What do you finally see? What does this prove? Is the diagram correct?

5. What is salt water, a compound or a mixture? You can perform this experiment at home.

6. Could you demonstrate the difference between a mixture and a compound with iron filings and some powdered sulphur? (*Hint.* One property of iron is that it is attracted to a magnet. Heat often helps elements to unite.)

7. Could you assemble the nine elements always present in protoplasm? You can obtain nitrogen in relatively pure form from the air. Air consists principally of nitrogen, oxygen, and carbon dioxide. You can remove the oxygen from a jar of air by burning carbon in it. You can then remove the carbon dioxide by introducing limewater. Nitrogen will be left. Hydrogen can be prepared by passing a current through water or by adding hydrochloric acid to zinc. Consult a chemistry book. *Do not have a flame on the desk.*

8. Try the test which has been discovered for detecting starch. Obtain a water solution of iodine crystals and potassium iodide. Add a few drops to some starch in water. Mix the iodine solution with sugar, protein (white of an egg), fats (butter, lard, or olive oil), table salt, and water. What is your result in each case? Why do you add iodine to these other substances? However, you have not repeated the chemist's experiment since you have not tried iodine with a vast number of other compounds.

9. Try the test which has been discovered for detecting simple sugars. Dissolve some grape sugar in water. Add either Fehling's solution or Benedict's solution. Heat the mixture until it boils. What is the final color of the substance? Do you get the color change with any substance other than simple sugar? Why do you test these other substances? Do your classmates get the same results?

10. Try the test that has been discovered for detecting proteins. Mix some of the white of an egg with dilute nitric acid. Boil the mixture for a few seconds. What color change do you notice? Now add ammonium hydroxide. What is the second color change? What else must you do? Why?

11. Try the test for detecting fats. Rub a bit of butter on a piece of unglazed paper. Hold the paper to the light. The spot that appears on the paper is called a *translucent* spot. Why? All fats leave a translucent spot on paper. Do substances other than fats produce this spot?

12. Try the test that has been discovered for detecting water. Boil some water in an open dish. Hold a dry, cold glass tumbler over the boiling water. What forms on the sides of the glass? Heated water vapor condenses when it strikes a cold object. If you try this test on the other substances you may get the same results. Explain.

13. Try the test for detecting mineral compounds. Burn a substance which you think contains minerals. Since minerals do not burn, at least not at the low temperature at which the other substances burn, they will remain as a white ash. What becomes of starch, sugar, fat, and protein when they are burned?

14. Cut as thin a section of raw potato as possible, mount on a slide in water, and tease the piece apart. Can you see cells? Add iodine solution.

15. A variety of yellow slime mold may be found on rotting wood. Slime molds may also be obtained from biological supply firms. Mount some bits of this plant material on slides and examine them under the microscope. What characteristic of protoplasm do you note?

Problems for Classroom Discussion

1. If you were given several bottles of colorless and odorless gases, some of which contained O, some H, and some N, how could you tell which was which?

2. Explain what is meant by the statement: A gas burns but does not support burning. To which gas that you studied does this statement apply? Which gas supports burning but does not burn? Which gases neither support burning nor burn?

3. Are the gases oxygen, nitrogen, carbon dioxide, and water vapor, which make up the air, *mixed* together or is air a compound? Give scientific evidence for your answer.

4. (*a*) The chemist speaks of water as H_2O. What is the meaning of 2 after the H? Carbon dioxide is CO_2. What are the proportions of C and O? (*b*) Carbon monoxide consists of carbon and oxygen. The prefix "mon" means one. Write the formula for carbon monoxide. (*c*) Ordinary granulated sugar is $C_{12}H_{22}O_{11}$. What do you know about its composition?

5. To show that you understand what carbohydrates are, make up five imaginary formulas each of which would fit the definition.

6. Make a list in two columns of the things that surround you. In one column put those that are living or are the products of living things. In the other, put the strictly lifeless things.

7. *Summary.* You should now have definite ideas about protoplasm. State in a numbered list first what the chemist knows about elements, compounds, and mixtures. Then, looking over one paragraph at a time, list the important ideas about the make-up of protoplasm. Then add what the biologist has learned about living matter.

8. *Unit Summary.* Combine the summary of Problem 1 and the summary which you have just made. You now have the answer to your unit question. What is it that you have learned?

Activities for the Junior Biologist

1. Prepare a demonstration other than that used in the text to show how elements change their nature when combined into compounds.

2. If several biology and chemistry texts are available, copy the definitions of the words element, compound, mixture. Examine them to discover how the definitions are alike. Do you think that some are better than others? Why?

3. Prepare a demonstration of the compounds found in living things. Try to get many different examples of each class of compounds: many starches, many sugars, and so on.

4. Test parts of many different plants and animals for starch. Prepare a chart showing which plant and animal parts contain large amounts of starch (giving a positive test) and which do not.

5. It would be interesting to do the same thing for simple or reducing sugars, proteins, fat, and water.

6. If you can get some amebae from a supply company or find them in a stagnant pool, you could demonstrate contractility and reproduction of protoplasm to the class. Amebae may be found on the under side of water plants, such as the pond lily, and on the surface of the mud at the bottom of a shallow pond. Collect some of this material and examine it a day or two later under the microscope. If you find amebae, transfer them to a beaker containing about 50 cc. of sterile pond water and two boiled wheat grains. Examine the culture each day. When the number of amebae in the original culture becomes large, start a fresh culture. Transfer some of the amebae to another beaker containing sterile pond water and boiled wheat grains. You must continue to do this to prevent the amebae from dying out. Ask the class secretary to write to General Biological Supply Co., Chicago, Ill., for a Turtox leaflet on protozoon cultures.

Good Books to Read

Carlson, A. J. and Johnson, V., *Machinery of the Body.* Univ. of Chicago.

Goldschmidt, R., *Ascaris, The Story of Biology.* Prentice-Hall.

Hegner, R. W., *College Zoology.* Macmillan.

Hunter, G. W., Walter, H. E., and Hunter, G. W., III, *Biology.* American Book.

Locy, W. A., *Biology and Its Makers.* Holt. *Growth of Biology.* Holt.
Shipley, A. E., *Life.* Macmillan.
Singer, C., *The Story of Living Things.* Harpers.
Sinnott, E. W., *Botany.* McGraw-Hill.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.

UNIT II. HOW DO PLANTS AND ANIMALS OBTAIN THEIR FOOD?

Problems

1. How Do Green Plants "Eat"?
2. How Do Green Plants Use the Simple Compounds They Take In?
3. How Do Animals Get Their Food?

Problem 1. How Do Green Plants "Eat"?

What kind of substances do green plants "eat"? The foods you eat, beefsteak, milk, bread, candy, and so on, are obviously not the food of a plant. It has no way of obtaining these even if it could use them. Then what does it eat? You will remember that protoplasm is made of carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, and some other elements. The plant could not be made of protoplasm unless it had taken these elements into itself at some time.

Now these chemical elements, like most others, are rarely found as elements in nature. Compounds are more plentiful in our world. Besides this, scientists have discovered that except for oxygen a plant cannot make use of elements even when they are present. It therefore becomes your problem to learn where the plant can find simple compounds which will supply it with the necessary elements.

What simple compounds are within reach of the green plant? To begin with, the plant is surrounded by air. This is a mixture of various gases, three of which are always present under normal conditions: the elements nitrogen and oxygen, and the compound carbon dioxide. Here is one simple compound that the green plant takes in or "eats." It can supply two of the necessary elements; namely, carbon and oxygen.

But there must be other compounds that enter the plant; compounds that supply the hydrogen, nitrogen, sulphur, phosphorus, and perhaps other elements. All of these come from the soil, in which the ordinary plant is rooted. Water (H_2O) enters in large amounts, as you know from the fact that you must keep watering your house plants regularly to keep them alive. But the water is not pure water; in it are dissolved some of the simple mineral compounds which make up the soil.

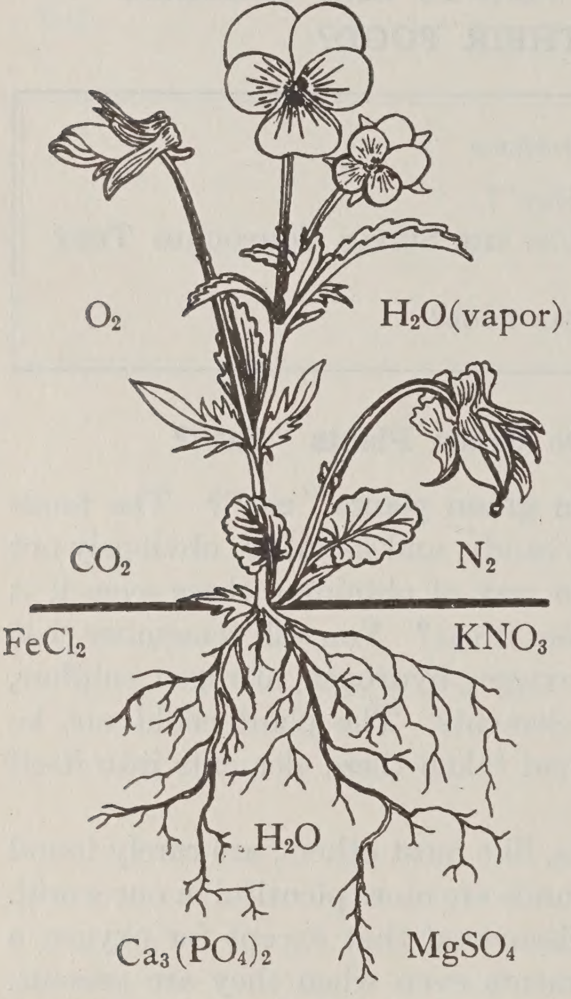


FIG. 150. Which of the substances around the plant are elements, which compounds? Which might the plant "eat"?

What mineral compounds are taken in by the plant? Since you know that the carbon dioxide and water between them supply only C, O, and H, you can conclude that the minerals must contribute the other necessary elements, N, S, P, Fe, and so on. As a matter of fact there are in the earth various kinds of *nitrates* (ny′traits), *sulphates*, *phosphates*, *iron compounds*, and many others. A common nitrate is *potassium nitrate* (potassium, nitrogen, oxygen); *magnesium sulphate* (magnesium, sulphur, oxygen) and *calcium phosphate* (calcium, phosphorus, oxygen) are also common minerals in the soil. Thus by taking in these various compounds the plant gets all the elements it needs, C, O, H, N, S, P, Fe, Mg, and so on.

Some of the mineral compounds that make up ordinary soil are not taken in by plants. And some are used by one species of plant and not by another. Different species growing side by side will take in compounds of slightly different make-up. It is a good thing that plants do not all take in exactly the same substances from the soil. If they did, the mineral compounds in the soil would be used up much faster than they are. But the important thing to remember is that a plant, under normal conditions, always takes in some form of nitrate, phosphate, and sulphate. All of them enter dissolved in water from the soil, known as *soil water*.

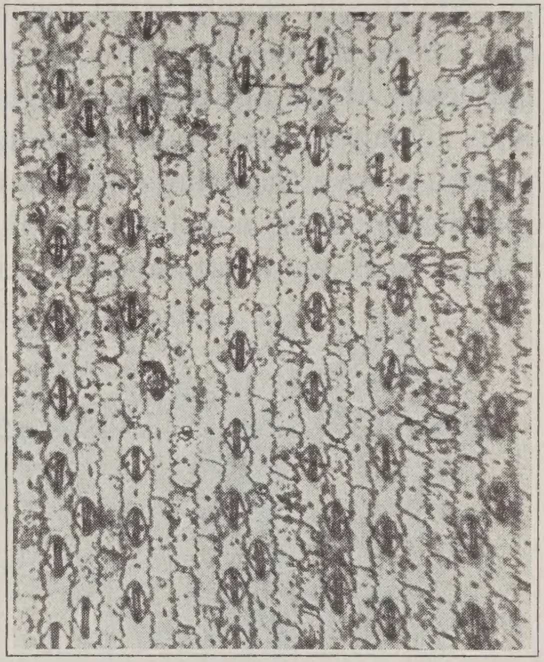


Photo by T. A. Kieselbach

FIG. 151. This epidermis of a corn leaf shows many stomata. Each shows as a dark line. What do you see on either side of a stoma?

Where are the mouths of a plant? Most animals have one mouth but a plant has countless mouths all over its surface. Some of them are fitted for taking in air; others, soil water. Those that take in air are situated, as you would expect, on the leaves and to some extent on the stem. They look a little like human mouths. Those which take in soil water must, of course, be underground on the roots. You would never recognize them as mouths. All these mouths, both those above and those underground, are almost constantly in use; unless its leaves fall and it rests during the winter months the healthy plant never stops "eating."

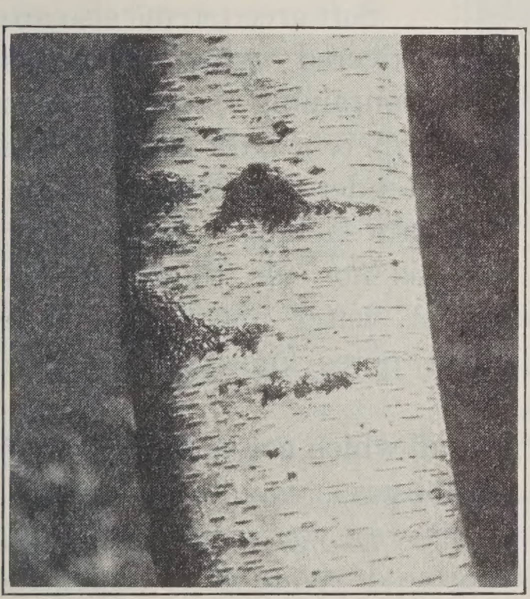


Photo by H. Schneider and J. Schwartz

FIG. 152. The thin, smooth bark of this birch tree shows many lenticels. Can you name another tree with conspicuous lenticels?

What is the nature of the mouths above ground? Every leaf, thin as it is, has a covering both on its upper and on its lower side. This is the *epidermis* (ep-i-der′miss). It consists of cells closely fitted together, so as to make a tough skin. But among these cells, at frequent intervals, especially in the lower epidermis, there are different cells. Each is shaped like a kidney bean. They always come in pairs and they are placed together in such a way that there is an opening left between them. This opening serves as a mouth and is called a *stoma* (stoh′ma). This is the Greek word for mouth. Air enters through these mouths. The two cells (called *guard cells*) enclosing the stoma can curl up or straighten out more or less like your lips, thus making the opening larger or smaller. *Exercises 1, 2.*

The *stomata* (stom′a-ta, plural) are extremely numerous. A medium-sized cabbage leaf probably has about 11,000,000 stomata and a sunflower leaf as many as 13,000,000.

Soft green stems also are covered with epidermis containing stomata, but where a bark replaces the tender skin true stomata are lacking. If the bark is not too thick, the exchange of air and the evaporation of water may take place through larger and more complicated pores known as *lenticels* (len′ti-cels).

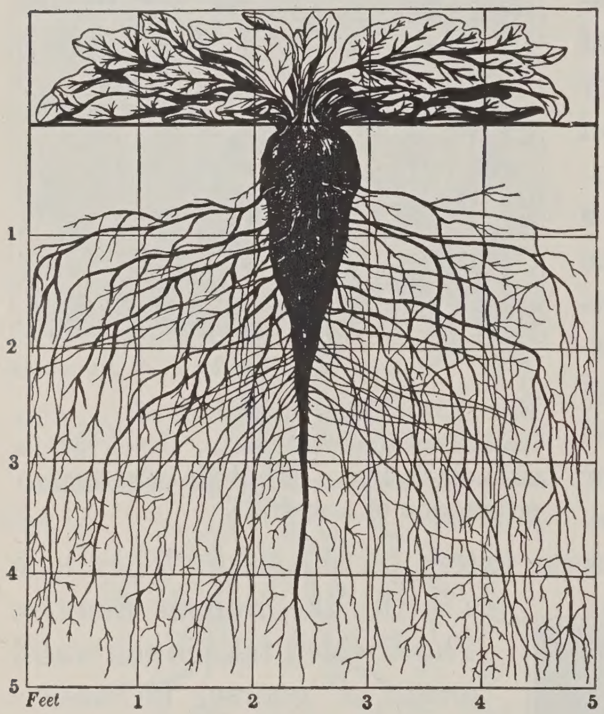


FIG. 153. The sugar beet has one main root, much thickened. It is called a *tap root.* Through how many square feet of soil do its branches spread?

What are the structures below ground which act as mouths? If we were buried up to our waists an observer would get quite a false impression of us. But that is the way you see most plants. Half of the organism is beneath the ground, the roots often reaching out as far as the stem with its branches. The farther out and down the roots extend, the better will be their chances of anchoring the plant in a storm and of obtaining the large amounts of water and minerals needed. Occasionally there is one main root corresponding to the main trunk of a tree, but more frequently many roots start off through the soil in many directions. In either case the larger roots are divided into smaller and smaller rootlets just as a stem branches into finer and finer twigs. The smallest rootlets may be so small that one can scarcely see them; the finest twigs which bear leaves are thick and clumsy in comparison. *Exercises 3, 4, 5, 6.*

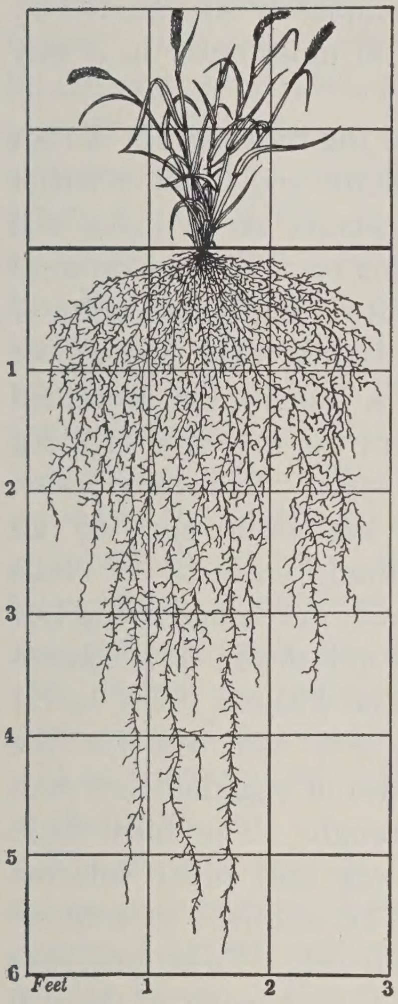
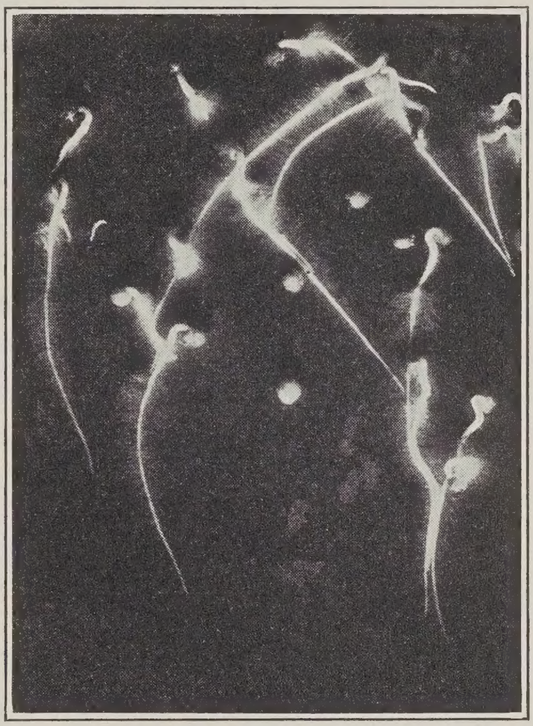


FIG. 154. Fibrous roots of the wheat. Note how far they reach. Can you explain when such roots are useful to the plant?



© *P. Blakiston's Son & Co., Inc.*

FIG. 155. Sprouting seeds showing a young root with root hairs. Where on each root are the shortest root hairs? If root hairs grew at the very tip what would happen as the root pushed through the ground?

When you use a strong magnifying glass to examine these finest rootlets (ordinary uprooting, of course, destroys these parts), you find each surrounded by a delicate, fuzzy covering consisting of tiny hairs, called *root hairs.* You can see how numerous these root hairs must be. *Exercise 7.*

Each root hair is nothing more than an outgrowth from a single cell. Like many other plant cells it has only a thin layer of cytoplasm lining the cell wall; the interior is completely occupied by a large vacuole. The root hairs are the mouths which take in the water and mineral matter for the plant. Of course, they are mouths of an unusual kind; they are not openings with lips. Since each root hair is living cytoplasm completely surrounded by a membrane, the soil water which comes in must enter in a way new to you.

How do water and other materials enter the root hairs? A root hair is so small that it would be impossible for you to see whether water enters it. But you can easily construct an artificial cell large enough for you to observe what is going on. You can do so as follows: Fill the bowl of a thistle tube with a little raw white of egg and some sugar solution. Then tie tightly over the top of it a membrane obtained from the intestine of a pig or sheep. This membrane, having been part of an animal, consists of cells which were once living but are now dead. It is a membrane without holes, as far as you can see, for the white of egg does not leak through. The filled bulb is like an enormous cell. The white of egg and sugar solution correspond to cytoplasm and cell sap. The animal's membrane acts like the membrane around the root hair cell. To be sure, this artificial cell has glass walls; but at least some portion of the cell has a membrane covering it.

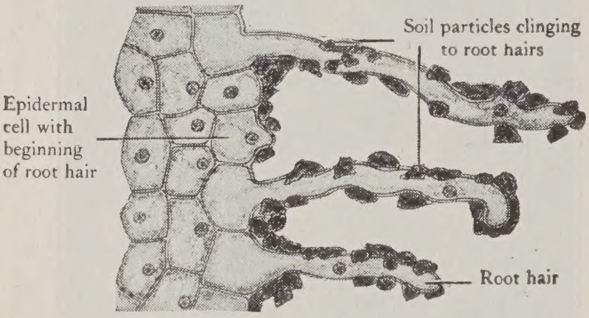

Soil particles clinging to root hairs
Epidermal cell with beginning of root hair
Root hair

FIG. 156. A cell wall and membrane surround each root hair. Which structures lie inside?

This artificial cell is then lowered into a tumbler of water (bulb down) and is allowed to stand for an hour or two. At the end of that time one sees a great change: the liquid has risen in the tube. That is, there is more liquid in the artificial cell now than when it was first lowered into the water. Apparently, water from the tumbler traveled *up* through the membrane and mingled with the sugar solution and white of egg. Water passed through the membrane into the artificial cell.

What can so readily be seen happening in this experiment is what occurs in every root hair cell. Just as water passes through the membrane which covers the mouth of the thistle tube, so water passes through the membrane surrounding the living cell. Every drop of soil water which enters a plant enters in this way. *Exercise 8.*

How can you explain the passing of water through the membrane? To answer this question you must first consider how liquids and other substances behave when they come in actual contact with one another, with no membrane between. If, with a medicine dropper you carefully deposit a few drops of thick molasses (a brown liquid) at the bottom of a tumbler of water and allow it to stand where it will not be moved, the molasses will spread through the water very, very slowly until the tumbler is filled with a brownish liquid. As you know from experience, when you put sugar into tea, stirring will hasten the process, but even without stirring the sugar will in time, sweeten all parts of the drink.

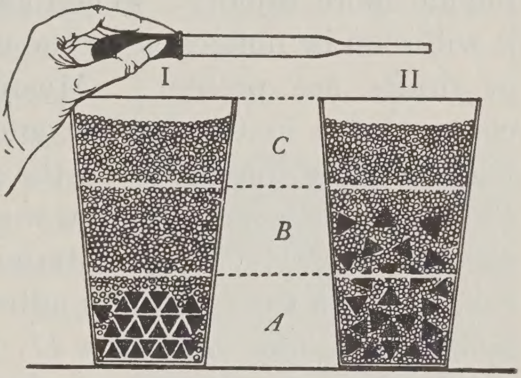


FIG. 157. Sugar molecules are shown as triangles, water molecules as circles. In I, sugar molecules (molasses) have just been put in with a dropper. II shows what has happened after a short time. Why have sugar molecules appeared at level *B*? Compare the number of water molecules at level *A* in I and II. Explain. Draw the tumbler as it would look after longer standing. Draw it as it would look if half as much molasses had been introduced.

The chemist tells us that all substances consist of invisible particles known as *molecules* (moll′e-kiools). The molecules (particles) of molasses or sugar, as also the molecules of water, continually bounce about and thus send themselves and each other in all directions within the water. In this way as the molasses molecules bounce about they will send themselves into the region where originally there was no molasses. So, too, the water molecules will bounce into the region which was originally occupied by molasses molecules. That is, each substance will spread from the region where its molecules are close to one another (highly *concentrated*) to where the molecules are farther apart (less concentrated). Concentration does not mean amount. In one drop of molasses the molecules are just as close to one another or just as concentrated as they are in a whole barrel of molasses. The difference is, naturally, that the barrel has many more molecules than the drop. But the *number* of molecules is not of direct importance; it is their closeness to one another (concentration) that forces them to spread. *Exercises 9, 10.*

What is true of the molecules of liquids bouncing about and intermingling is also true of gases. But in gases the molecules are less closely associated and bounce about more actively and intermingle more rapidly. When gas escapes from the kitchen stove it will soon be noticeable in the next room, even if no air currents or drafts are present. Meanwhile the gas has become less concentrated in the kitchen and molecules of air have bounced back into the spaces left by the gas as it passes out. The gas and the air, like the molasses and water, have intermingled quite irrespective of gravity. This intermingling is called *diffusion.* Among solids, where the molecules adhere (stick together) closely, there is little diffusion. *Exercises 11, 12.*

What happens when a membrane separates liquids? You have learned how liquids and gases intermingle or diffuse when there is no membrane between them to interfere with their passage. The experiment with the thistle tube described above seemed to show that substances diffuse through membranes, too; water certainly passed from tumbler to tube. Sugar also passed through the membrane; if you had tested the liquid in the tumbler for sugar you could have proved this. Each substance spread from the region in which it was more concentrated to the region in which it was less concentrated, passing through the membrane on its way.

When this experiment was set up, the thistle tube contained sugar dissolved in water. The water molecules were therefore less concentrated inside the thistle tube than outside; for outside there was nothing dissolved in the water. Inside the thistle tube, the sugar solution may have been 90% or 95% or even 99% water, depending on the strength of the sugar solution used. But certainly the concentration of water molecules was less within the thistle tube than in the tumbler; therefore, water diffused inward. The sugar diffused through the membrane because it was more concentrated within the tube than outside. There was no sugar at all outside when the experiment was set up. This diffusion of substances through a membrane is given a special name: *osmosis* (os-moh'sis).*

How long will the sugar continue to pass out through the membrane by osmosis? If the conditions are suitable, until the concentration of sugar is the same on both sides of the membrane. And water will diffuse inward until the concentration is the same on both sides. You may wonder what happens at this stage. As the result of many experiments, scientists have come to the conclusion that osmosis continues. But since the concentrations are the same on both sides of the membrane, the sugar and water move into the thistle tube as fast as they move out. You would see no further change.

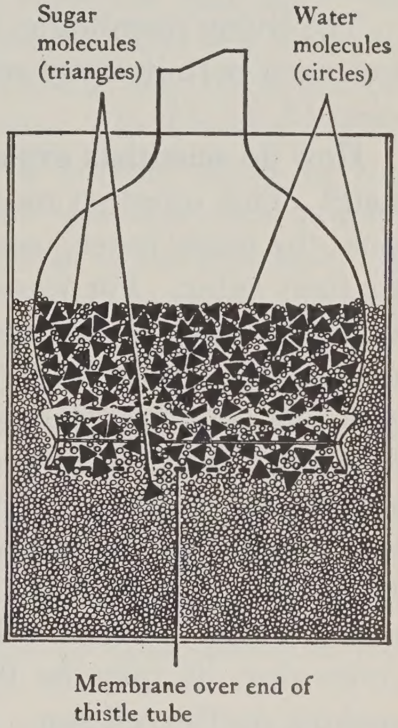

Sugar molecules (triangles)
Water molecules (circles)
Membrane over end of thistle tube

FIG. 158. Sugar molecules have begun to pass through the membrane. Since water molecules are smaller and close together, will sugar or water molecules be more numerous within a given space? Which kind will stand the best chance of bouncing through the membrane? Would water or sugar travel more rapidly by osmosis?

Under what conditions are molecules able to pass through a membrane? Substances like sugar and common table salt *dissolve* in water. That is, when placed in water, their molecules separate and diffuse through the water. They are said to be *soluble* in water. Some substances do not diffuse in water. If shaken up in water they may appear to do so for a time. But if the mixture is permitted to stand the particles will fall to the bottom. These substances are said to be *insoluble;* they do not dissolve. Starch and protein are such insoluble substances. There are many others. Some, like fat, are insoluble in water, but are soluble in other liquids. Fat is soluble in ether, for example.

These substances which do not dissolve or diffuse in water cannot pass through a membrane by osmosis. Scientists explain this by saying that their molecules or groups of molecules are too large for the tiny openings of the membrane. The living membrane which is found around every cell body has holes which do not permit the large molecules of starch, fat, and protein to pass through. These substances therefore cannot enter or leave by osmosis.

---

* The term osmosis is used somewhat differently by chemists.

The living membrane, like some other types of membrane, will not even permit every soluble substance to pass through. *Exercises 13, 14, 15.*

How do scientists explain the passing of soil water into the root hair? This question must be divided into two parts: first, how does the water enter; second, how do the dissolved salts (mineral matter) enter. For in osmosis the movement of each substance is independent of the movement of every other. The root hair is completely surrounded by a membrane. The vacuole within the root hair contains cell sap which is a solution of various substances in water. Because of the many compounds dissolved in the cell sap the concentration of water is relatively small. The soil water on the other side of the membrane is a weak solution of minerals; it has few minerals and a relatively large percentage of water. In other words, the weak solution has a great concentration of water molecules; it may be 97% water as compared to 80% water making up the cell sap. As a result, water will pass into the root hair.

Should the soil water happen to be a very concentrated solution (have much mineral matter and comparatively little water), osmosis of water would take place in the reverse direction; the plant would lose water through its root hairs and dry up in consequence. The osmosis of water in the wrong direction takes place when large amounts of salt are sprinkled on the ground, sink down, and dissolve in the soil water. Perhaps you have seen how, under these circumstances, the grass gets yellow rapidly and soon dies. However, under normal conditions water does not leave the root hairs; it continually passes in.

How do the nitrates, sulphates, phosphates, and other mineral compounds enter the root hair? They are dissolved in the water of the soil and are able to pass through the openings of the membrane. When the movement of these minerals is traced the passage of each mineral must be considered separately. In many cases some of the minerals dissolved in the soil water are present in higher concentration outside than in the cell sap. Therefore these minerals will pass from the soil *into* the root hair. But the movements of minerals are not always simple; there is much about osmosis that is not understood. *Exercise 16.*

What happens to the substances that enter the root hair? As more and more water enters the root hair, the cell sap tends to become a weaker and weaker solution. That is, the concentration of the water molecules inside grows greater. You would expect its concentration, therefore, gradually to become equal to the concentration of the water outside. But this does not happen because the water that enters does not remain in the root hair. It passes by osmosis to a neighboring cell. Thus the sap in the root hair cell again becomes a solution having a low concentration of water and containing much mineral matter. So conditions remain as they were at the beginning and water keeps flowing into the plant.

The same is true of some mineral substances; they do not have an opportunity to become concentrated in the root hair. They are passed right on to the next cell toward the interior of the root. Eventually, both water and minerals pass to other parts of the plant.

"Eating" is thus a very complicated process in a plant. But the plant has taken only the first step toward obtaining food. The simple compounds which enter through the mouths must be changed a great deal before they can be thought of as real food.

Exercises

1. What is the structure of the epidermis of a leaf? Narcissus, Tradescantia, or many other leaves may be used. With a scalpel and a pair of forceps remove a bit of the epidermis from the lower surface. Scrape it until you have a very thin membrane and mount in a drop of water. Examine it under low power. Do you see the tiny openings or stomata? Study the cells that enclose them. How do these cells differ in shape from the other cells of the epidermis? How many of these cells enclose a single stoma? What are they called? Are the stomata always the same size? Explain. Draw a portion of the epidermis showing all of the structures that were mentioned. Label.

2. Are there more stomata in the upper or lower epidermis? Remove small pieces of epidermis from the lower and upper surfaces of a leaf. Examine each under low power. What differences do you note? Count the stomata in the field of vision. How could you arrive at an estimate of the number of stomata on each surface of this leaf?

3. How may roots of different plants vary in form? If living forms cannot be obtained, use charts or pictures. Examine the roots of carrot (or beet), grass (or corn), and dahlia (or sweet potato). Draw. These are good examples of the *tap* root, *fibrous* root, and *fascicled* (fass′i-keld) root. The carrot and beet live for two seasons; the grass dies at the end of the first year. What might be the use of the tap root?

4. What type of root gives the firmest anchorage? Try to uproot a carrot and a small grass plant. What do you notice? Explain.

5. How do the roots of a young bean plant compare in extent with the parts above ground? Uproot a young bean plant raised in sawdust and wash the root system clean. Measure the lengths of the main stem and of the root. Now measure the spread of the longest branches and of the longest side roots. Compare the total length of the stems with that of the roots. Make a diagram to show the proportions.

6. How can some plants use roots above ground? Examine the stalk of a corn plant some distance above ground. What do you notice? What might be the function of these aerial (air) roots? Examine closely the older stems of an English or Boston ivy. Describe. What might be the function of these aerial roots? Write a summary table entering: name of plant, description of root, function or functions of each.

7. How can you grow roots showing root hairs? Lay six mustard or radish seeds (peas or corn may be used but will grow much more slowly) on moist blotting paper in a saucer. Cover with a glass plate. Do not allow the blotting paper to dry. Examine the roots every day with a magnifying glass. Do not touch them. Why? Record your observations. Root hairs may also be grown by placing a Tradescantia cutting in a test tube of water.

8. To show that water passes through a membrane. Set up an experiment as described in the text. Completely fill the bulb. Mark carefully the level in the thistle tube after it has been lowered into the tumbler. How soon do you notice any change? Record. Examine again after 24 hours. Keep careful notes.

9. Do gases spread from one place to another by themselves? Fill a small bottle with oxygen. Cover with a glass and stand on a table. Place a bottle of the same size, filled with air, over the mouth of the bottle of oxygen after removing the glass plate. Seal the mouths together with a strip of adhesive tape. Let stand for 15 minutes. Remove the upper bottle without disturbing the lower. At once thrust a glowing splint into the upper bottle. What do you observe? What is lacking in this experiment? How could you improve on it?

10. Do substances other than gases intermingle? Drop a crystal of copper sulphate into a tall jar of water and allow to stand without disturbing. Take careful notes. Into the bottom of a tumbler of water standing quietly on a table carefully place some red ink with a medicine dropper. Do not stir the water. Record observations. If you wished to convince someone else of the truth of what you learned what would he want to know? Have you given all that information in your notes?

11. Does water rise in the thistle tube if it is filled with plain water?

12. Would water from the tumbler enter the thistle tube if it were filled with air? Try it. Study the next paragraph in the text. Explain.

13. How could you find out whether red ink passes through a membrane? Set up an experiment. Record your results.

14. Does starch pass through a membrane? Boil some starch in water, making a "starch paste." Fill the bulb of a thistle tube with this. Cover with a membrane. Invert in a tumbler of water. Mark the level of the liquid in the thistle tube. After the experiment has been standing for several hours, find out whether starch has passed through the membrane. How can you do this? Has the liquid risen in the thistle tube? Write your method, results, and explanations.

15. Will all kinds of membranes permit water and dissolved substances to pass through? Set up experiments using membranes of rubber, cellophane, oiled silk, and so on. Can you explain the results in each case?

16. How does soil water differ from pure water? Soak soil in a flower pot so that there is more water than the soil can hold. Let it stand for an hour. By pressing the soil, pour off the extra water into a funnel lined with a fine cloth. Collect the water that drips through. How does the water look? Boil this water in an evaporating dish (or test tube if necessary) until the water is evaporated. Does anything remain?

Problems for Classroom Discussion

1. In the sixteenth century a chemist placed a small tree weighing 5 pounds in dry soil weighing 200 pounds. After 5 years the tree weighed 169 pounds and the soil had lost only 2 ounces in weight. What interesting conclusions can you draw about the relative amounts of the various substances that enter the plant?

2. Why may the study of the chemistry of the soil be considered an important branch of agriculture?

3. Draw a diagram to show the appearance of a stoma and its enclosing guard cells during (*a*) moist weather, (*b*) dry weather. Explain.

4. Why is it good to wash the leaves of a house plant occasionally?

5. Three billion molecules of pure water are separated by a membrane from a salt solution containing six billion molecules of water and two billion molecules of salt. In which direction would the more rapid flow of water through the membrane take place? Why? Will the salt molecules move through the membrane? Why?

6. How can you make sliced peaches juicy for serving? Why?

7. To freshen lettuce would you recommend plain water or salt?

8. If weeds spring up in the paths around your house what is a possible way of killing them?

9. Why cannot a farmer successfully grow the same kind of plant on the same piece of land year after year? Explain how he helps himself out of this difficulty.

10. Why does it usually take a plant which has been transplanted some time to recover?

11. *Summary.* Look back over each paragraph title. State briefly the answer to each question. Bring these answers together into one paragraph. You will then have an answer to the problem question.

Activities for the Junior Biologist

1. Read Problem 1 above. Could you devise an experiment on a small scale in which you could compare the amount of water by weight that enters a plant with the amount of carbon dioxide?

2. How does the lack of minerals affect the plant? Grow pea seedlings in moist sawdust. When they have used up their stored food grow them in the following solutions. (Only the roots should be under water.)

Solution 1. (all minerals present)

Water (distilled)	1 liter
Calcium nitrate	1 gram
Magnesium sulphate	0.25 gram
Potassium acid phosphate	0.25 gram
Potassium chloride	0.10 gram
Ferric chloride	2 drops

Solution 2. (no nitrogen) Use calcium sulphate instead of calcium nitrate.

Solution 3. (no potassium) Use sodium chloride instead of potassium chloride and sodium sulphate instead of potassium acid phosphate.

Solution 4. (no magnesium) Use calcium sulphate instead of magnesium sulphate.

Solution 5. (no calcium) Use sodium nitrate instead of calcium nitrate.

Solution 6. (no iron) Omit the ferric chloride.

How is the rate of growth affected by the lack of the various minerals? Are all parts of the plant similarly affected? Make a chart showing your results.

3. Using wax or any other plastic substance make a model of a small root. Use hairs to represent root hairs.

4. Report on the economic importance of roots.

5. How do root hairs cling to the soil? Raise root hairs as described in Exercise 7, but sprinkle some very finely powdered soil on the blotter. When you have a good crop of root hairs, carefully examine the root hairs on one of the seedlings with a strong magnifying glass.

6. It would be interesting to see whether the amount of moisture affects the development of root hairs. Raise germinated oat or mustard seeds under different moisture conditions under glass.

7. Can osmosis be speeded up by changing the concentration of water in the thistle tube? Fill one tube with thick molasses (there is much sugar so that the water molecules are not concentrated). Fill another tube with diluted molasses (there is little sugar so that the water molecules are more concentrated). Set each in a jar of water. How soon can you see results of osmosis in each tube? How much rise do you get in each?

8. Do you suppose temperature might influence the rate of osmosis? How might you try to find out?

9. Osmosis of several substances can go on in both directions at the same time. Set up an experiment to show this and demonstrate it to the class. Use sugar and table salt.

10. You could show the class the result of sprinkling salt or too much fertilizer on the soil in a pot of growing seedlings. (Plant 20 or 30 lentils. Let them grow until they are two or three inches tall.) Could you set up an experiment with a thistle tube to explain what happens?

11. When did farmers first start rotating crops? Why did they do it? We now know several other good reasons for doing it. Look up the subject and report to the class.

12. Make a collection of different kinds of bark to show lenticels and mount them on a large cardboard.

13. Could you devise some method of making a good-sized model of a root and another one of a single root hair cell?

14. Prepare a demonstration of the minerals found in ordinary soil. Look up activity 2.

Problem 2. How Do Green Plants Use the Simple Compounds They Take In?

How do you know that air and soil water must be changed within the plant? In an earlier chapter you learned that starches, sugars, fats, and proteins are found in plant and animal cells. But in the last problem you read that the only substances that enter the plant are air and soil water. There is no doubt, therefore, that in some way the plant puts air and soil water together to make such substances as starch, sugar, fat, and protein. These are larger and more complex compounds than carbon dioxide (CO_2) and water (H_2O). Starch, you will remember, is $C_6H_{10}O_5$ and sugar, $C_6H_{12}O_6$. Putting together simple things to make more complex ones is ordinarily called manufacturing; the chemist calls it *synthesis* (putting together). *Exercise 1.*

Now carbohydrates, complex as they are, are simpler than the fats and proteins. When the plant begins to manufacture or synthesize it begins by making carbohydrates. But even carbohydrate synthesis is a complicated process and scientists studied it for many years before they understood it.

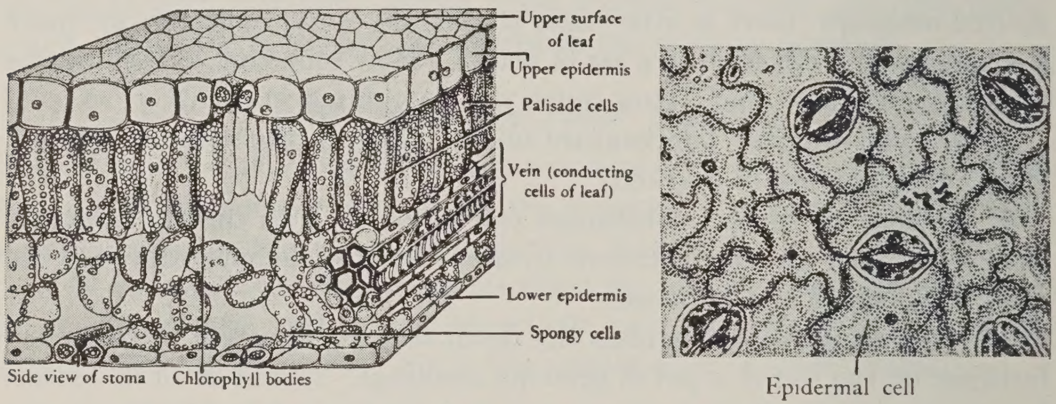


FIG. 159. A tiny piece of a leaf magnified. Where do you find chlorophyll bodies? What must be in the "empty" spaces between the spongy cells?

A tiny piece of lower epidermis. How many stomata do you see?

In which portions of the plant are carbohydrates manufactured? Although there are living, active cells in every organ of the plant, only some of them can take part in the manufacture of starch or sugar. It seems that a cell is unable to combine air and soil water unless some of its protoplasm happens to contain a striking green coloring matter known as *chlorophyll* (klor′o-fill). This chlorophyll lies within special structures known as chlorophyll bodies (*chloroplasts*). The chlorophyll seems to help in the synthesis of air and water into sugar and starch. Thus it is only organs which are green, namely the leaf and some of the younger stems, which can manufacture carbohydrates. When leaves lack chlorophyll, as is sometimes the case, they cannot make carbohydrates. *Exercises 2, 3.*

What is interesting about chlorophyll bodies? Chlorophyll bodies contain yellow coloring matters as well as the green chlorophyll which manufactures carbohydrates. The chlorophyll itself is a mixture of two compounds each made up of C, H, O, N, and the element magnesium. The only way you can obtain it in the laboratory is to dissolve it out of the chlorophyll bodies by means of alcohol. In some plants it dissolves out easily; in others heating is necessary.

Chlorophyll forms only in the presence of light although the yellow substances need no light for their formation. If you sprout a plant in the dark it will not be green. On the other hand, strong light causes the chlorophyll to decompose or disappear and a leaf exposed to light looks green only because its cells are active and new chlorophyll is constantly being formed. In the fall, as the time for their death approaches, the leaves begin to form less chlorophyll. It is then that the yellow coloring, which has been hidden by the green, shows up, giving the brilliant yellow tints to some autumn foliage. In some leaves, as the chlorophyll fades a new red coloring appears. While low temperatures favor its formation, it is not merely frost which causes leaves to turn red. *Exercise 4.*

Why can chlorophyll bodies do their work for only part of the twenty-four hours? It was noted long ago that green leaves do not contain starch at all hours. When tested late in the afternoon, the leaves prove to contain starch. But leaves of the same plant, when tested early the next morning, show no trace of starch. This seemed to show that starch was made only during the day and was disposed of during the night. Perhaps the factory runs only during the day, during the hours when there is light? Perhaps light is necessary for the chlorophyll bodies to do their work? To find out whether this guess, or *hypothesis* (hy-poth′e-sis), was correct, biologists performed the following experiment. They kept a plant in darkness for a day or two, then put it into the bright sunlight and wrapped one of its leaves in black paper. In this way they had one leaf of a plant exposed to the light and another leaf on the same plant in darkness; both leaves contained chlorophyll bodies, they were getting the same food, had the same temperature, and in other respects were being exposed to the same conditions. When, after several hours, two such leaves were tested it was found that the exposed leaf contained starch while the one which had been covered lacked it. It looked as though carbohydrate making really were dependent on light. Of course, biologists performed this experiment, or some variation of it, again and again before they agreed that their hypothesis was right. After that they spoke of carbohydrate manufacture as *photosynthesis* because *photo* comes from the Greek word for light. *Exercise 5.*

How does the leaf manufacture carbohydrates in the light? All day long while the sun is beating on the broad flat surface of the leaf, chlorophyll bodies gathered just beneath the upper epidermis absorb the light rays. Some rays pass right through but others are kept inside. Meanwhile air is entering and in this air is a trace of carbon dioxide. Water which is continually being absorbed by the root hairs is passing through the stem and through the pipes in the veins of the leaf. Then, with the aid of the light energy captured by the chlorophyll bodies, there occurs a chemical union of the carbon dioxide and water. The result of this union is, as you might expect, a carbohydrate. *Exercise 6.*

CO_2 and H_2O contain all the elements necessary for making $C_6H_{10}O_5$ (starch) and it would seem simple to combine them. But, in reality, the process is very complicated and several other substances are made first. Scientists studied the process for many years before they understood it and only very recently did they learn to imitate in the laboratory what plants have always done within their green cells. Even now the scientists can produce only tiny amounts of sugar and starch at great expense. When man wants sugar or starch for practical use he must go to the plant.

To keep up the steady process of carbohydrate manufacture, the plant uses up large amounts of the raw products, water and carbon dioxide. As a result, while air is circulating in the leaf it loses its carbon dioxide to the cells. Therefore, the air passing out of a leaf (if its cells are actively engaged in photosynthesis) will have little or no carbon dioxide. When the cell combines water and carbon dioxide to make the new product, sugar or starch, the gas oxygen is left over. So the air within the air spaces of the leaf not only loses its carbon dioxide but gains large amounts of oxygen. Most of this oxygen diffuses out into the surrounding atmosphere. In a dense forest region where all the millions of leaves are using up carbon dioxide and releasing oxygen in the daytime the surrounding atmosphere becomes changed. Such air would tend to have more oxygen and less carbon dioxide than the air over a city. But because of the movement of air (winds) a rather thorough mixing takes place so that the oxygen set free by such masses of green plants is carried to other parts of the world where there may be less carbohydrate manufacture. *Exercise 7.*

Courtesy Department of Conservation, Michigan

FIG. 160. How would the air over the hills in the background tend to differ from the air over a desert?

How does the plant obtain the proteins and fats found within its cells? Proteins and fats cannot be absorbed from the ground; they too must be manufactured by the cells. But biologists understand even less about the manufacture of protein than they do about photosynthesis. It is known that chlorophyll plays no part in fat and protein synthesis and that light is not necessary. Proteins can be made in any cell of the plant provided it has carbohydrates and is supplied with soil water. Soil water contains nitrates, sulphates, phosphates, and various other minerals. These supply certain elements necessary for making protein. Entering through the root hairs, the stream of soil water flows steadily up through the roots, the stem, the finer twigs, and into the leaves. As the soil water passes along, the minerals drop out here and there, in this cell and that. They are then combined with starch or sugar. In this way there is formed a compound consisting of C, H, O, N, S, P, and several other elements.

Even though chlorophyll, the substance so characteristic of plants, is not required, it is only plant cells that have the power to manufacture protein out of these simple compounds. Fats contain the same elements as carbohydrates, and seem to be made from starch and sugar.

How do colorless plants provide themselves with carbohydrates? In Chapter X you read about such plants as mushrooms and other fungi which are colorless. These colorless plants lack chlorophyll. Obviously, such plants cannot make carbohydrates out of simple compounds. Although they are unable to move about and eat in the sense in which an animal eats, they succeed in obtaining their food in much the same way as do animals. When you know more about the ways in which animals use foods, the answer to this question will be easier for you.

Exercises

1. What are some of the compounds present in the root of a plant? Test some root such as the carrot, for starch, sugar, and protein. Which are present? Test the leaf for starch. Before you can do this, you must perform Exercise 2.

2. How can chlorophyll be dissolved out of the leaf? Boil a leaf in a beaker of water for a few minutes. The boiling softens the leaf and makes it easier to extract the chlorophyll. Pour off the water and in its place add some alcohol. Place the flask in a water bath and heat. (**Caution:** Do not heat alcohol directly over flame.) What indications are there that the chlorophyll is being dissolved out of the leaf?

3. How can you prove that the presence of chlorophyll is necessary for carbohydrate synthesis? For this experiment you will need plants with leaves partly green and partly white, such as green and white coleus, silver leaf geranium, or variegated tradescantia. Place the plant in the sunlight for several hours. Remove one or two leaves and test them for starch. You must be sure to dissolve out the chlorophyll first. Does this experiment have a control? Would it be as good to use a leaf that is completely white? Explain. (*Note.* You use the starch test because it is easy to show starch in a leaf. The plant makes sugar first and later changes it into starch.)

4. How does the inside of a leaf look? You may make your own cross sections. Split a pith rod lengthwise. Insert a small portion of a leaf between these halves at the top of the rod. Then cut crosswise through the pith thus cutting through the leaf at the same time. Mount the thinnest sections in a drop of water and cover with a cover glass. Examine under low power. How can you tell which is the top and which the bottom of the leaf? Directly under the upper epidermis you can see closely packed oblong-shaped cells. These are called the *palisade* cells. Can you guess why this name is used? The cells under the palisade cells make up what is known as the *spongy layer*. How are these cells arranged? Notice that the stomata open into air spaces inside the leaf. All of the air spaces are connected with one another. In your section you may see some circular groups of cells with thick walls. These are veins. What do you suppose is their function? In which of the cells of the leaf does most photosynthesis take place? Why? Draw and label all of the structures mentioned.

5. Devise a variation of the experiment in the text to find out whether light is necessary for photosynthesis. Which is the better experiment? Why?

6. Does a plant need carbon dioxide for photosynthesis? Place two small potted geranium plants in small drip pans of water. Keep them in a dark closet for a day. Then test a leaf from each plant for starch. Do you expect to find it? If starch is not present, proceed. Place one plant, still in its pan, in a wider pan partly filled with clear limewater. Make sure the limewater does not reach the plant. Cover the plant with a bell jar, the bottom of which is in the limewater. Follow the same procedure with the second plant but put plain water in the large pan. Limewater absorbs carbon dioxide. Allow both bell jars to stand in the dark for several hours. How does the air in one bell jar then differ from the air in the other? Place both plants in the sunlight for several hours. Test a leaf from each plant for starch. Record your results. What conclusion could you draw if these results were obtained many times?

7. Demonstration by teacher. The release of oxygen by a green plant can be demonstrated if advantage is taken of the fuming of white phosphorus (**danger!**) in the presence of oxygen. (The reaction forms phosphorus pentoxide.) A piece of white phosphorus is fastened to a cork which is then used to close one end of a large glass tube about one inch in diameter. Water is poured into the tube, leaving a space of three or four inches clear. Elodea plants are introduced and the tube then closed by means of a second cork. When the tube is inverted so that the phosphorus is in the air space, fuming occurs. After a time all the oxygen will have been removed from the air. The glass tube is then turned so that the phosphorus is in water. After having been kept in the bright sunlight the tube is inverted again. Fuming occurs a second time showing that the Elodea plant must have released oxygen. The demonstration may be repeated several times.

Problems for Classroom Discussion

1. Why do farmers often permit their potato plants to grow to the end of the season before harvesting the crop?

2. What do you recommend for taking out grass stains?

3. Why is the normal arrangement of palisade and spongy layer cells better than the reverse arrangement?

4. Why may leaf-eating insects kill a tree?

5. How does the arrangement of leaves on a shade tree indicate that light is necessary for photosynthesis?

6. How must celery plants be treated to make them white?

7. Do you see any deeper meaning to the statement, "Bread is the staff of life"?

8. *Summary.* Write a brief answer to each paragraph title; combine these into one paragraph. Can you now answer the problem question?

Activities for the Junior Biologist

1. What is the effect of a strong electric light upon the leaves of a plant? Start some bean seedlings in moist sawdust, then transplant to soil. Use plants of the same size. When the cotyledons have shriveled place half of the plants under a strong electric light at night. Keep all of the plants in sunlight during the day. Compare the growth of the leaves of both groups. Has the electric light made any measurable difference? Try the starch test on a leaf from each of the two groups of plants. What do you find? Explain.

2. Which of the sun's rays does chlorophyll use? Pass a strong beam of light through a test tube containing chlorophyll in solution. Place a prism in the path of the beam after it has come through the chlorophyll. Study the spectrum that is produced. Which colors pass through the chlorophyll? Which does the chlorophyll use?

3. Can you notice any difference between the gases released by a plant not engaged in photosynthesis and one in which photosynthesis is going on? Devise an experiment to demonstrate this.

4. Look up and report on the artificial production of sugar from carbon dioxide and water. Is this process commercially useful?

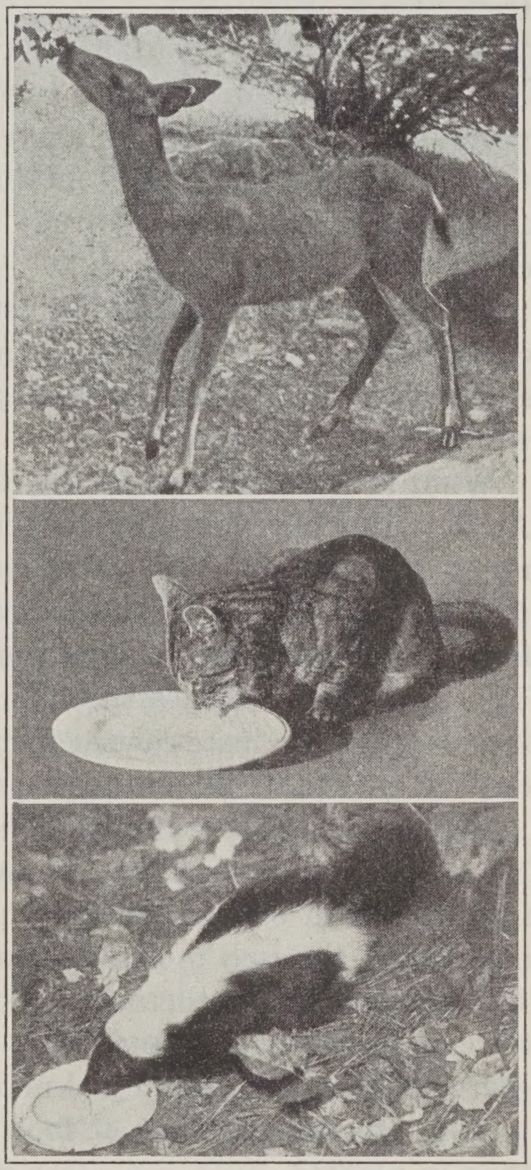
5. Devise an experiment to show the effect on chlorophyll formation of growing plants in the dark.

Problem 3. How Do Animals Get Their Food?

What do animals eat? Your dinner may consist of soup, chicken, potatoes, spinach, cake, and milk. A lion in the jungle may dine on tender antelope steak; an elephant may make a meal of the leaves and inner bark of twenty small trees; an anteater may swallow a quart of struggling ants; and a kingfisher may snatch a trout out of a stream.

The animals in the sea prey on smaller forms or feed on seaweeds or decaying plants or animals. The microscopic animals may stuff themselves with tiny bits of plant or animal food; sometimes they take in a living organism, if they can find one small enough to be taken in whole. In short, there are almost as many kinds of food as there are animals to do the eating.

What do all the foods of animals have in common? The animal you know best, man himself, eats a vast variety of foods. Bird's-nest soup, blubber of whale, caviar, candy, and catsup, as well as all the other foods you could name, are different in looks and taste. Yet, endless as are the variations in the foods of animals, the foods are really alike in their general make-up.



Photos by Prof. H. H. Johnson, H. Schneider and J. Schwartz, and Frank Gehr

FIG. 161. What nutrients is each of these animals getting in its food?

All of them are either the cells of plants or animals or substances made by the cells. All foods therefore contain the same compounds that are found in the cell: sugars, starches, fats, proteins, minerals, and water. By using the tests for these substances on your foods you can show that this is so. The proteins, sugars, starches, and fats are sometimes spoken of as *nutrients* (new'-tree-ents).* *Exercise 1.*

But not all foods contain all the compounds found in the cell. Some foods have only one or two or just a few. Candy is almost pure sugar; lean meat is largely pure protein; and so on. But there are other foods that contain many of the compounds; milk, for example, has all but starch; and nuts, too, have most of the compounds.

Of course, foods contain substances other than the proteins, carbohydrates, fats, minerals, and water. In many cases these substances are of no importance; a few have special uses which will be discussed later.†

What is the source of all the different foods eaten by animals? At first thought you may be tempted to say that there are so many sources that you could not name them all. But a more careful examination of the situation will disclose an interesting fact. The antelope on which the lion dines ate grass and leaves. The trout that supplies the kingfisher with a meal probably ate insects; but the insects went to the plant for their own food. So did the ants that slide down the anteater's throat.

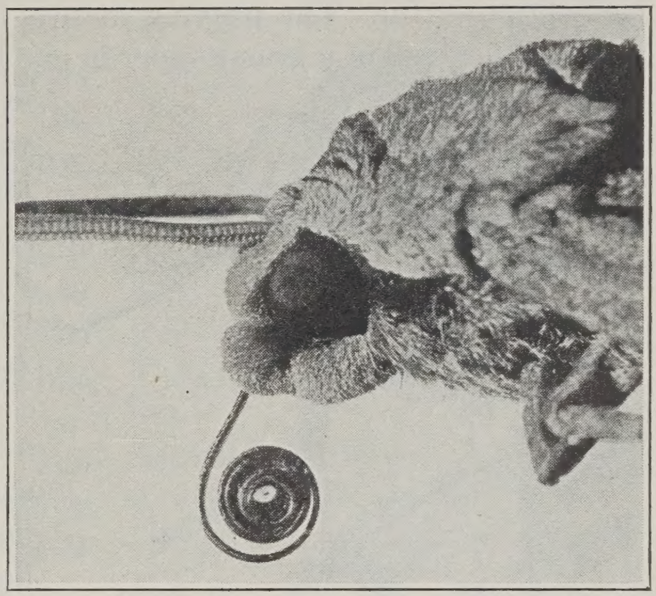
In every case the animal depends on the plant for its food. Either it obtains the nutrients and other food substances directly from the plant or it obtains them from the plant indirectly; they may come through a plant-eating animal which serves as food. The green plant is, therefore, the true source of all the nutrients for both meat-eating and plant-eating animals. It is also the source of most of the mineral matter.

Why are the methods of food getting in animals more varied than in plants? It is not surprising that the absorbing organs of different kinds of green plants are usually much alike. They all take in soil water and air. The animals, however, eat such a great variety of plant and animal foods that one would expect their methods of food getting to vary considerably. Some of them eat

---

* The word nutrient is sometimes used to include mineral matter and water also.

† Some authors speak of vitamins as nutrients. We have preferred to call vitamins *accessory food substances.*



Courtesy Gen. Bio. Supply House

FIG. 162. Of what advantage is it to the moth that the sucking tube is coiled?

grasses, some browse on trees, some suck the juices out of plants; meat eaters may feed on any species of animal from the smallest invertebrate to a large-sized mammal; they may find their food on land, in the air, or in the water. It is not astonishing that with such different *diets* (food usually eaten) animals should have different structures for food getting. Frequently, too, they have unusual habits associated with these structures.

In what different ways do insects feed? Earlier in the book you read that insects can live pretty nearly anywhere and eat almost anything. Of the more than half a million different species, some feed on the tissues of plants or other animals, some eat books or carpets or the timbers of our buildings. They eat our foods, of course, stopping short of almost nothing; even the box of cayenne pepper is not safe against the attack of one species. But in spite of the variety of foods there are only three main types of mouth parts. They are fitted either for biting, for sucking, or for lapping up liquids. Occasionally an insect has mouth parts fitted for both biting and sucking.

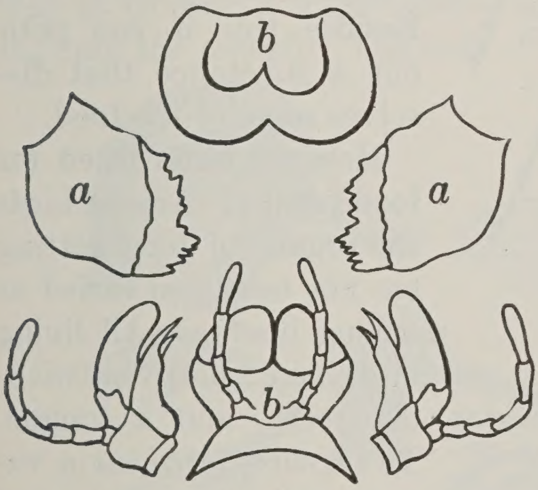


FIG. 163. Mouth parts of the grasshopper. The two strong, jagged jaws (*a*) move from side to side. They are covered by the lips (*b*). The jointed structures like short feelers hold and direct the food. (*Adapted from Turtox drawing.*)

The biting mouth parts, or jaws, may be sharp and extremely powerful. The praying mantis has no difficulty in snapping off the head of a grasshopper in one bite. Some insects tackle even larger prey; the giant water bug will attack and kill a small fish. Many insects use their jaws on plant food and develop very complicated mouth parts. *Exercises 2, 3.*

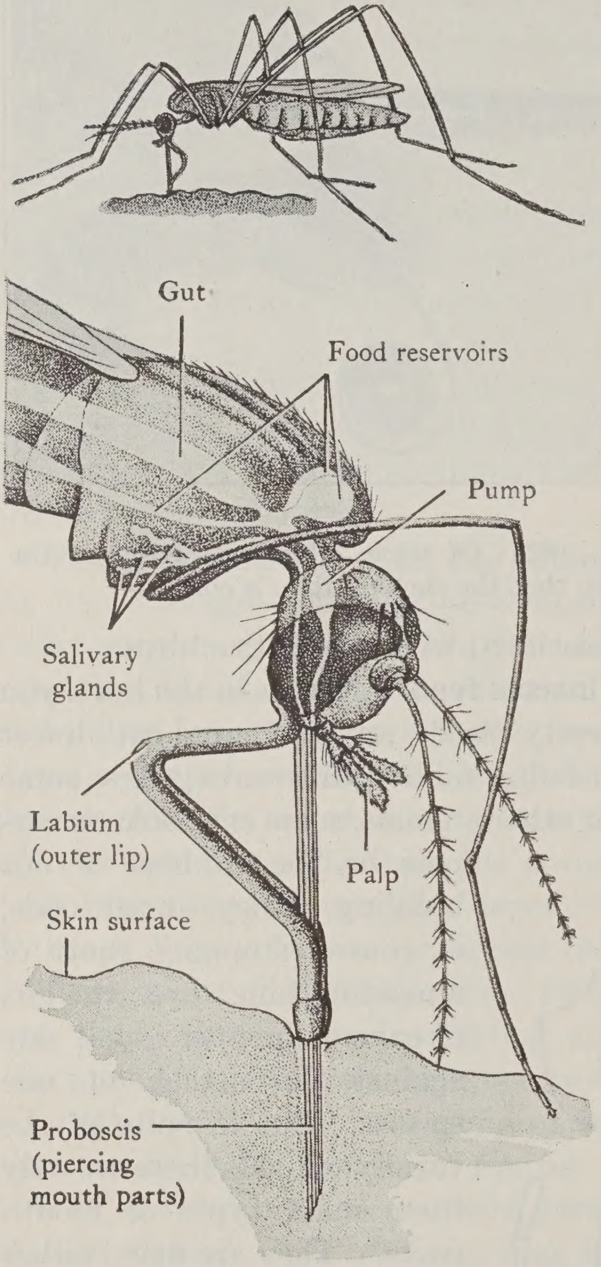


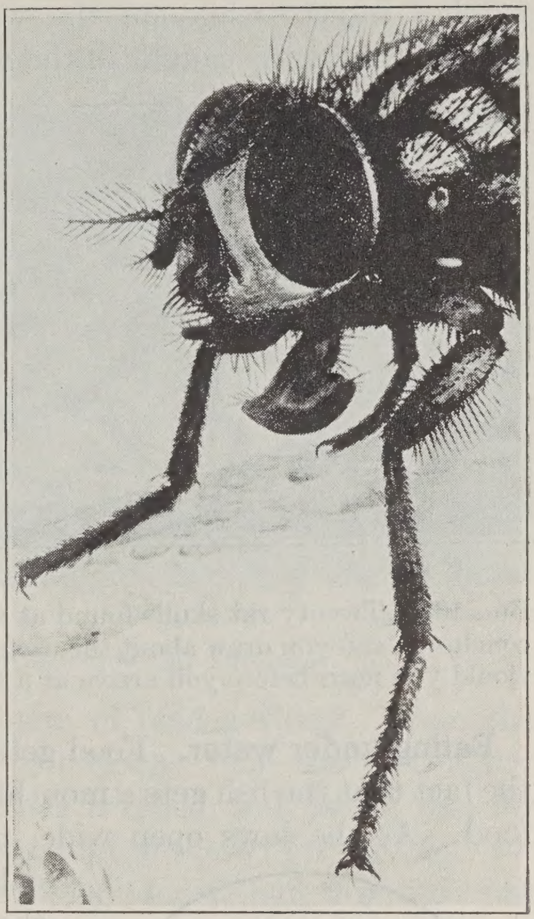
FIG. 164. The mosquito keeps its piercing mouth parts in a sheath when not in use. Do you see the tiny pump which sucks up the blood when the skin has been pierced?

Moths and butterflies use a long tube for sucking the sugary liquid made by flowers. But sometimes liquids are not so easy to get at. To suck juices from the leaves or stems or roots of plants some insects must be provided with organs for piercing as well as sucking.

The housefly, an example of an insect that laps its food, has rasping structures which break up solid food. Besides this it can pour out a substance that dissolves some of the food.

How are birds fitted for food getting? Among birds the organs of food getting are not nearly so varied as among insects. All living birds have a horny bill without teeth, and a tongue. To be sure, birds eat a variety of foods and the bill may take on various shapes.

You have already learned that the birds of prey have heavy, hooked beaks for tearing flesh. The duck has a very different kind of bill which is used for scooping up food from the mud. The sandpiper is equipped with a long and slender bill for spearing small Crustacea or worms in the soft sand along the water's edge. The hummingbird's delicate bill, which is about one fourth the length of its body, is thrust far into the flower for its nectar. The woodpecker needs a strong but pointed bill to dig insects from deep within the bark. The goldfinch and all its many cousins, the various species of sparrows, have short, thick, and conical bills for cracking seeds. Some birds, like the flycatchers and the night-flying whippoorwill, have stiff bristles around the bill. You might think that these would be a hindrance in getting food, but they are arranged in such a way as to form a funnel leading into the mouth. The bird



Courtesy Amer. Mus. Nat. Hist.

FIG. 165. Have you ever seen the tongue of a housefly moving up and down as it lapped its food?

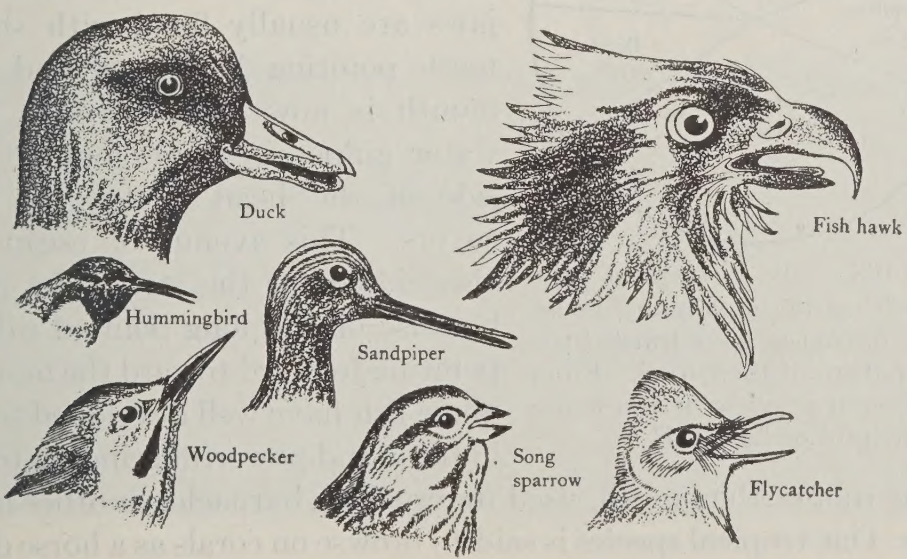
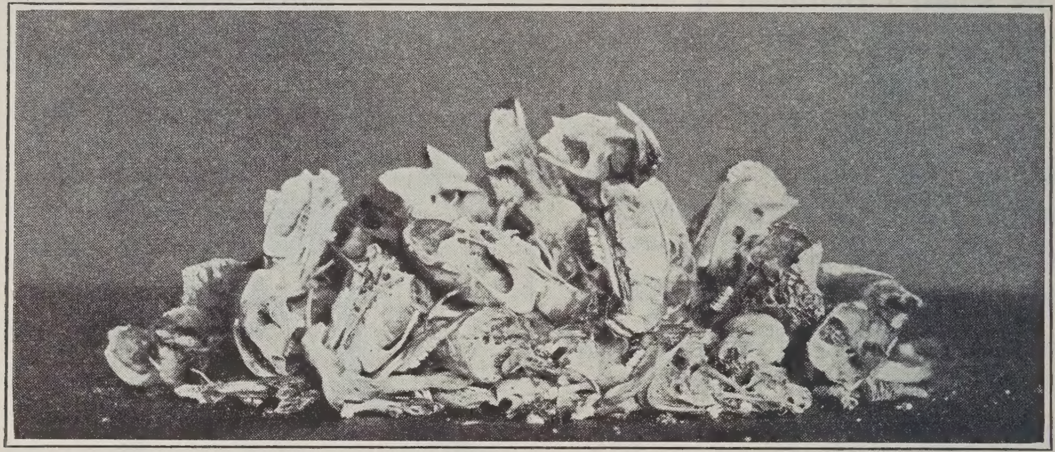


FIG. 166. Can you explain how each of these bills might be used?

catches insects while on the wing, and when it darts for its prey the insect is caught in the mouth of the funnel. *Exercise 4.*



Courtesy U. S. Bureau of Biological Survey

FIG. 167. Twenty rat skulls found at the nest of a pair of barn owls. What conclusion can you draw about the usefulness of owls? What further evidence would you need before you arrive at a final conclusion?

Eating under water. Food getting in the fish is complicated by the fact that the fish gets a mouthful of water every time it snatches food. As the jaws open wide, the cavity within is enormously enlarged, a current is created, and the unsuspecting prey is washed into the mouth. Once in, the odds are against the captive. There is no escape to the front for the jaws are usually lined with sharp teeth pointing backward and the mouth is now kept closed. The water gulped in passes out at the side of the head under the gill covers. This avenue of escape is also closed for the struggling prey because of the long pointed rakers pointing forward toward the mouth. Some fish have well developed teeth in front and powerful grinding teeth on the roof of the mouth, used for crushing barnacles or other hard shells. One tropical species is said to browse on corals as a horse does on grass. But as a rule the food is swallowed whole. *Exercises 5, 6.*

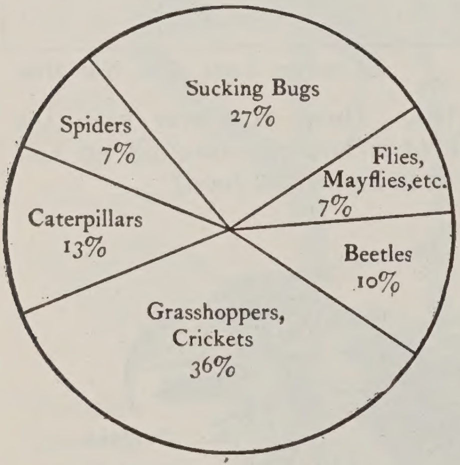
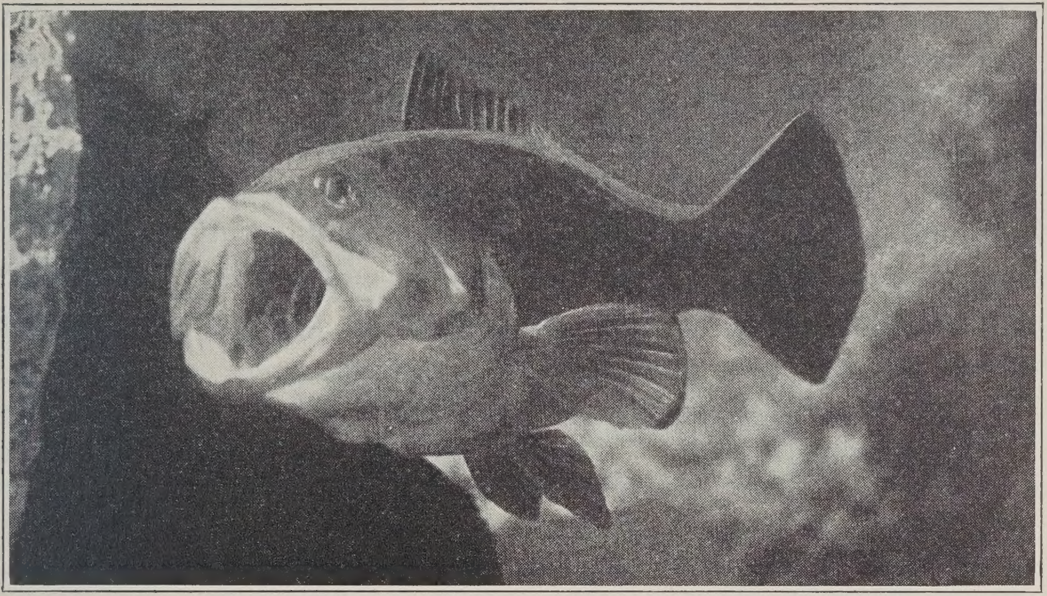


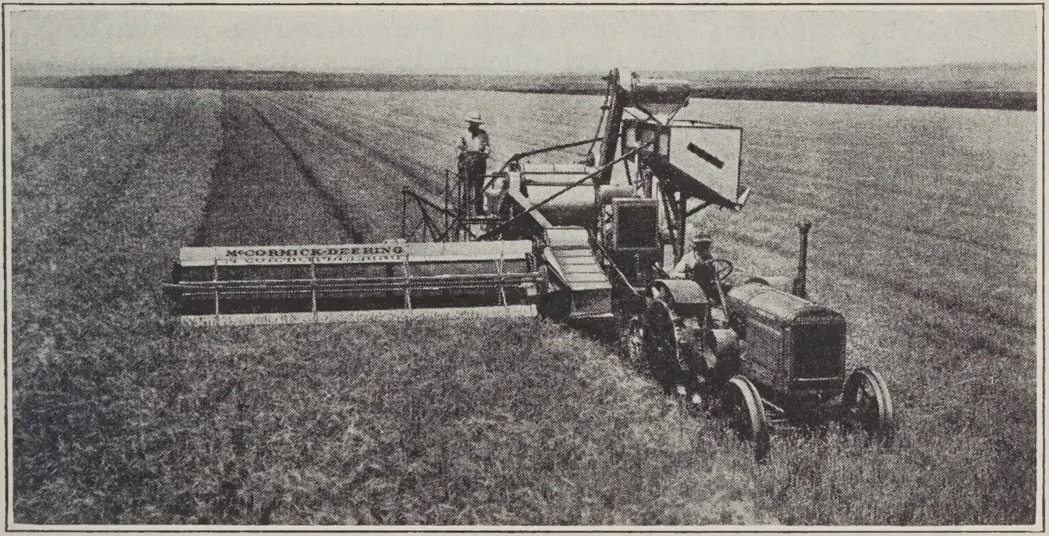
FIG. 168. By studying the stomach contents of many house wrens, biologists have learned the exact nature of their food. From man's point of view, is the house wren helpful or harmful?



Courtesy New York Zoological Society

FIG. 169. What a mouthful this fish can take!

How does man solve his problem of food getting? From the earliest times of which we have knowledge, man has used many devices for obtaining food. He has trapped and fished, dug for roots, stripped leaves from plants, and gathered fruits. But for several thousands of years man has done more than that. He has planted crops and raised cattle and poultry for his table. These activities were made possible by his understanding of how these organisms lived and by the invention of tools for tilling the soil.



Courtesy International Harvester Co.

FIG. 170. How does man's brain help him to get food?

In recent times the invention of machinery which can replace men has led to a revolution in the methods by which man obtains food. Nowadays vast portions of the earth's surface are devoted to food-getting activities like the raising of cattle and the planting of crops. The use of machinery has made this possible because all the work that needs to be done in sowing, tending, and harvesting a crop may be done so much more rapidly and over so much larger an area than formerly. Modern means of transportation have made it possible, too, for men to live far away from these areas devoted to food getting.

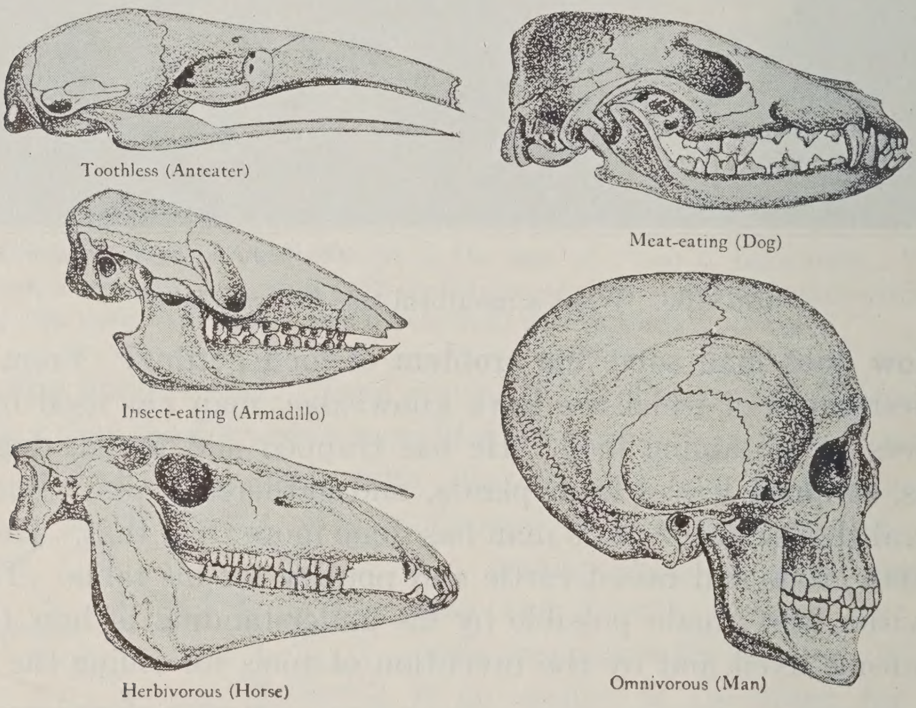


Fig. 171. Different kinds of teeth are found in various mammals. For what are the horse's teeth fitted? How can the dog use the long eyeteeth (incisors)?

Thus while man is equipped with no specially designed mouth parts for food getting and his hands are not at all equipped for digging or tearing he has been able to obtain foods of the most varied kinds and in large amounts. Man's brain and his hands, which can use man-made tools so well, have made this possible.

Exercises

1. Of what are some of our common foods composed? Apply the food tests to widely different foods; use dried peas, potatoes, a piece of fish, milk, nuts, banana, and any other common foods. Keep a careful record of your results. What have these foods in common?

2. How does the grasshopper eat? Place some grasshoppers in a large case together with pieces of grass sod. Observe. Is the motion of their jaws like yours? Explain. How are their jaws constructed to enable them to bite into the grass? How do the short antennalike structures below the jaws aid in feeding?

3. How does a butterfly eat? Use a net to capture some butterflies. Handle them with care so as not to injure them. Place them in a large case with some plants and some vials containing a solution of honey or molasses in water. Why must liquid food be used? How can you best describe the butterfly's method of feeding?

4. How can you show the economic importance of two common hawks? Make two pie charts (circle graphs) to show the following figures. Red-shouldered hawk stomach contents: mice and shrews, 28%; other mammals, squirrels, etc., 9%; small birds, 5%; poultry and game birds, 2%; insects, 35%; snakes and frogs, 20%; miscellaneous, 1%. Cooper's hawk: mice and other small mammals, 10.9%; small birds, 50.7%; poultry and game birds, 33.1%; lizards, 3.0%; insects, 2.1%; frogs, 0.2%.

These figures were obtained by government scientists who studied the contents of hundreds of stomachs. What conclusions can you draw about the economic importance of these hawks? Why can you not be absolutely sure about the usefulness or harmfulness of these hawks?

5. How does a fish obtain its food? Because of the fish's habitat, it is not easy to watch it feed. The examination of a large fish head, however, will give you some idea of how fish get their food. Secure a large fresh fish head from your fish dealer. Pry open its jaws as far as they will go. Keep the mouth open with a piece of wood. Compare the extent to which a fish can open its mouth with the extent to which you can open yours. How does this help a fish to capture its prey? What is the number and the position of the teeth? Feel them. Of what use might they be? Try opening the mouth of the fish while the head is under water. When the fish opens its mouth wide what happens to the surrounding water and the food that may be in it? Close the mouth. Must the fish swallow the mouthful of water? Where might it go? When the mouth is open notice the openings in back on either side of the mouth cavity. They lead to the breathing organs (gills) which open to the outside on the sides of the head. Do you find structures which would keep the food from passing out over the gills? Describe. These structures are called gill rakers. Can you now explain how the fish takes in and swallows food?

6. How does the frog eat? If no live frogs can be caught outdoors, obtain some from a supply house. Place one in a large battery jar with some wet moss and cover the jar with a screen. Throw in *live* food such as flies, roaches, young grasshoppers, or small worms. How does the frog capture its prey? You will have to observe very closely because the frog's movements are swift. You can verify your observations by examining the mouth of a preserved frog. Pull out the tongue. How does its point of attachment differ from yours? In life the tip of the tongue is covered with a sticky substance. Do these facts indicate to you how the frog must capture its food? Is this what you observed? A frog's teeth are very small. Feel the jaws. Where are the teeth? Does the frog chew its food or swallow it whole? Of what use might the teeth be? Write a summary of all your observations.

Problems for Classroom Discussion

1. Make a list of the first twenty foods that come to your mind. What is the source of each one? Trace it back to the *original* source in every case. What conclusions do you arrive at? Compare your list with those of your classmates.

2. Make a table summing up what you have learned about mouth parts in insects and enter the facts about as many different insects as possible.

3. In a table show what you know about the bills and food of birds.

4. Why is the study of the contents of birds' stomachs a more scientific way of learning what birds eat than watching them?

5. A scientist reported that he had examined the contents of the stomachs of 563 robins caught in Maryland in June. Using the figures he had obtained he stated the diet of the robins. In what ways was his work unscientific? How would you improve on it?

6. *Summary.* What is the best way of preparing a simple summary of this problem? Do it. Compare with your classmates' summaries.

7. *Unit Summary.* Look back to your summaries of Problems 1, 2, and 3. You have now answered the question "How do plants and animals obtain their food?" In finding the answer you have discovered one very important difference between plant life and animal life. Can you state this difference in a few words?

Activities for the Junior Biologist

1. Can you make a large chart to show in a striking way that the source of all animal foods is the green plant?

2. Look up and report on the various types of bait used by men who fish for sport. What does this tell you about the food of fish?

3. No one but a trained biologist ought to shoot birds for the purpose of studying their stomach contents. But you can find out a great deal about their diets if you watch them carefully. Keep notes. Why is nesting time best for this activity?

4. People often want to make pets of such animals as snakes or turtles, but do not know what to feed them. Look up and report on successful diets for these animals when they are in captivity.

5. If there are tropical fish or goldfish available, observe their feeding and prepare a report from your notes.

6. If there is a large library near by look up the economic importance of hawks in the *Ohio Journal of Science*, Vol. XXXII, No. 5, September, 1932. Other state journals or U. S. Department of Agriculture Farmers' Bulletins may be used.

7. Is the crow a useful or harmful bird? Look up federal reports and state agricultural college bulletins.

Good Books to Read

Gager, C. S., *General Botany*. Blakiston.
Hegner, R. W., *College Zoology*. Macmillan. *Parade of the Animal Kingdom.* Macmillan.
Hunter, G. W., Walter, H. E., and Hunter, G. W., III, *Biology*. American Book.
Keeble, F., *The Life of Plants*. Cambridge Univ. Press.
MacDougal, D. T., *The Green Leaf*. Appleton.
Osterhout, W. J. V., *Experiments with Plants*. Macmillan.
Shipley, A. E., *Life*. Macmillan.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life*. Doubleday.

UNIT III. HOW DO ANIMALS AND PLANTS USE THEIR FOOD?

Problems

1. How Do Living Things Grow?
2. How Else Do Animals and Plants Use Food?
3. How Should Man Plan His Diet to Make the Wisest Use of His Food?

Problem 1. How Do Living Things Grow?

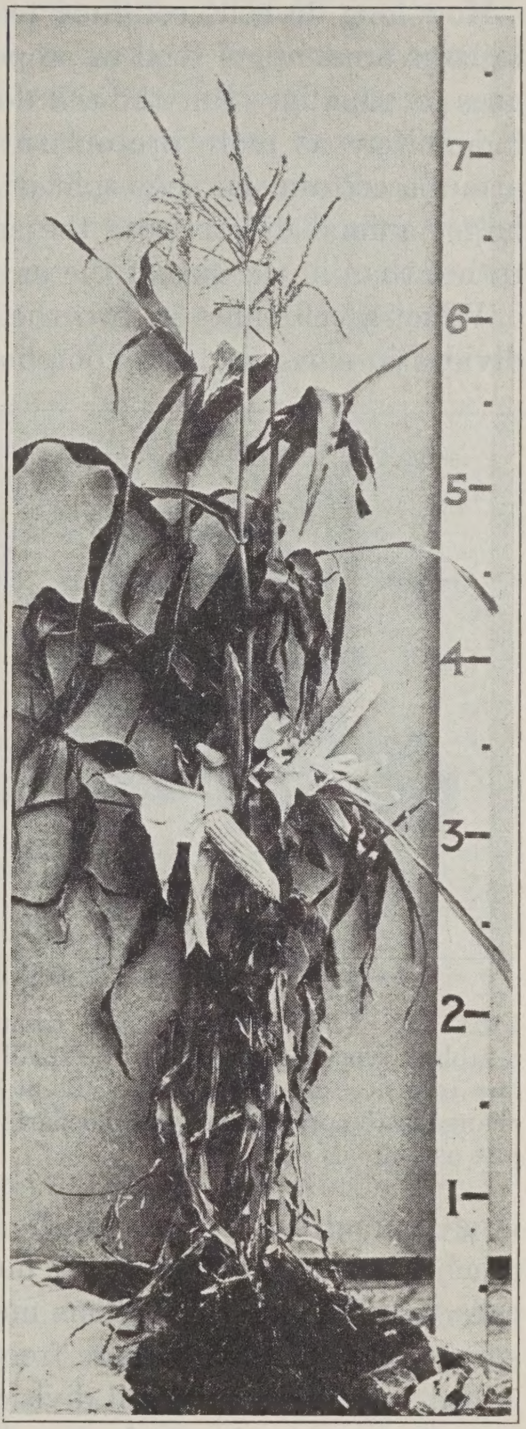
What is growth in living things? You often see lifeless objects becoming larger. A wall grows higher when one brick is laid on another. When a snowball is rolled through soft snow, more and more snow becomes attached to it. When you pile layer after layer of clothing on yourself you occupy more space. But in none of these cases is the word "growth" used as the biologist uses it. To him growth does not mean adding more material from without. It means adding material from within, material which has to be changed and made over into something else before it can be used to make the organism larger. After the new material has been added from within you cannot tell the difference between it and the material which was originally in the organism. *Exercise 1.*

And this growth goes on at a most surprising rate. When you were born you probably weighed about seven pounds. Within a year you had tripled your weight. Now you weigh many times as much as you did then and all the extra substance that is you was at one time something very different. It may have been milk and bread, or pea soup and sausages, or macaroni and cheese. You can no longer tell what it was.

A plant can do even more surprising things. In one short summer a tiny kernel of corn turns into a plant that towers far above your head. And what does it do that on? Water and an invisible gas and an ounce or two of solids taken from the soil.

How do living things grow? Living things are made of protoplasm. Since protoplasm is found in cells it is the cells that do the growing. The foreign material (food) is changed into protoplasm by the living matter itself. This process is known as *assimilation.* Assimilation is not well understood by biologists. All that is known is that certain substances can be changed into protoplasm. Protein must be one of them, since it is the only nutrient which contains usable nitrogen. However, protein is not the only material used. Fatty substances, mineral matter (salts), and water all go into the making of protoplasm.

But to a certain extent living things grow by a process other than assimilation. The plant cell may use carbohydrates and other substances to build a thick wall around itself. If enough cells do this the plant will increase in size. This, too, is considered true growth. In animals there may be true growth by the making of intercellular material. In bone tissue, for example, each cell builds a large amount of mineral matter around itself. In the end, this occupies more space than the bone cells themselves. *Exercise 2.*



Courtesy North Dakota Agr. Coll.

FIG. 172. How high is the corn plant? If it took four months to grow, what was its average daily increase in height?

How long do cells continue to grow? The young animal takes in large amounts of food in proportion to its size and assimilation goes on rapidly. But the cell does not keep on increasing in size indefinitely as more protoplasm is made. As soon as the cells attain a certain size they split or divide in two; that is, the older, larger animal differs from the smaller in the number of its cells rather than in the size of the individual cells. *Exercise 3.*

When a cell splits in two the nucleus always divides first. It divides in a regular and complicated way into two equal parts.* Then a groove forms around the middle of the cell body. The groove gets deeper, until there are two new cells, each with its own nucleus. In the case of plant cells which have firm cellulose walls, the cell body is not cut in two by a groove, but a wall of cellulose is laid down between the two recently separated nuclei. In either case the result is two small cells which through assimilation soon attain the normal size. Then they repeat the process of division. Thus the organism grows.

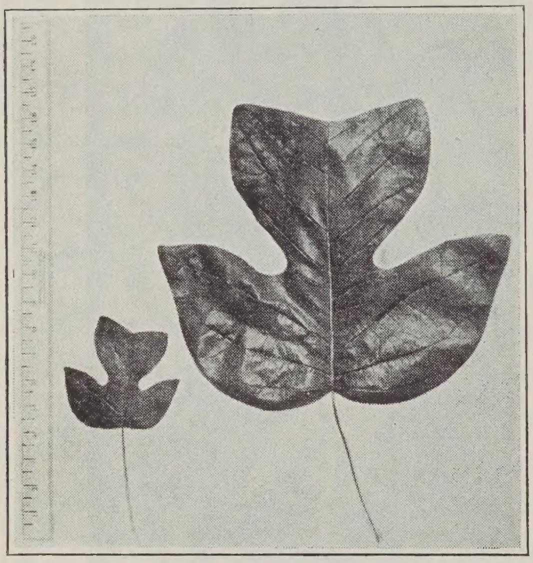


Photo by H. Schneider and J. Schwartz

FIG. 173. The large leaf came from a sapling (very young tree); the small one from a "grownup" tree. Plants change in the proportions of their parts just as animals do.

How long do the cells of animals continue to divide? In a large animal such as the giraffe this cell division continues for a much longer time than in the mouse; the giraffe has many more cells than the mouse, billions more. No one knows why in some species the cells divide more frequently and become so numerous.

But, in all animals, cell division never stops completely. It is true that many of your body cells divide only in the early stages of your life. Then they stop. This is true of muscle cells and nerve cells. But there are others that keep on dividing. The skin cells, for example, and the special skin cells that form the hair and nails never stop dividing.

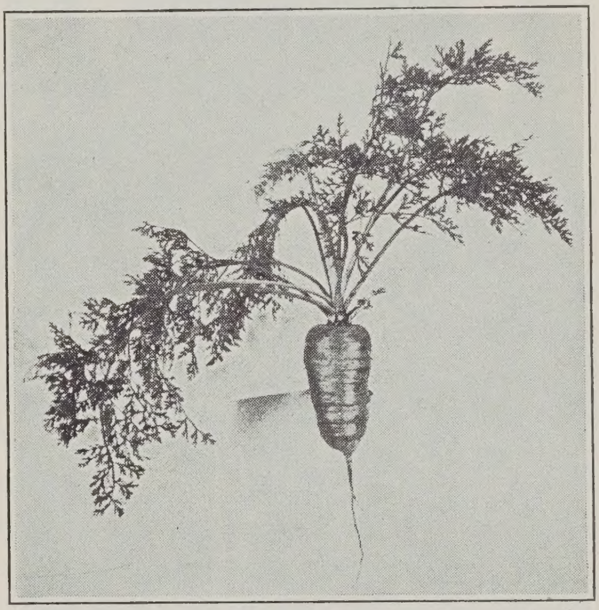
---

* This process is described in Part 3.

Why does assimilation go on throughout life? Even cells which stop dividing continue to assimilate and may continue their growth. A muscle grows because the muscle cells become larger, not because more cells are formed. In this way an animal changes its size somewhat even after it is "full grown."

But assimilation must continue after the animal has attained its normal growth for still another reason. More protoplasm is needed for repair. Your body does its repair work as soon as a little of the body material is used up or worn out. So little is done at a time and the whole process of repair is done on so small a scale that you are unaware of it. Except after unusual damage has been done, as by a cut, repair in you consists of the replacement of tiny parts of the protoplasm within the cell; you cannot expect to be able to see this process going on.

Of course, repair goes on even while the animal is growing. And it continues long after growth has stopped; for as long as the animal lives some of the food it eats is made into protoplasm for repair or replacement. In plants, too, the very same process goes on. Constant repair is characteristic of all organisms.

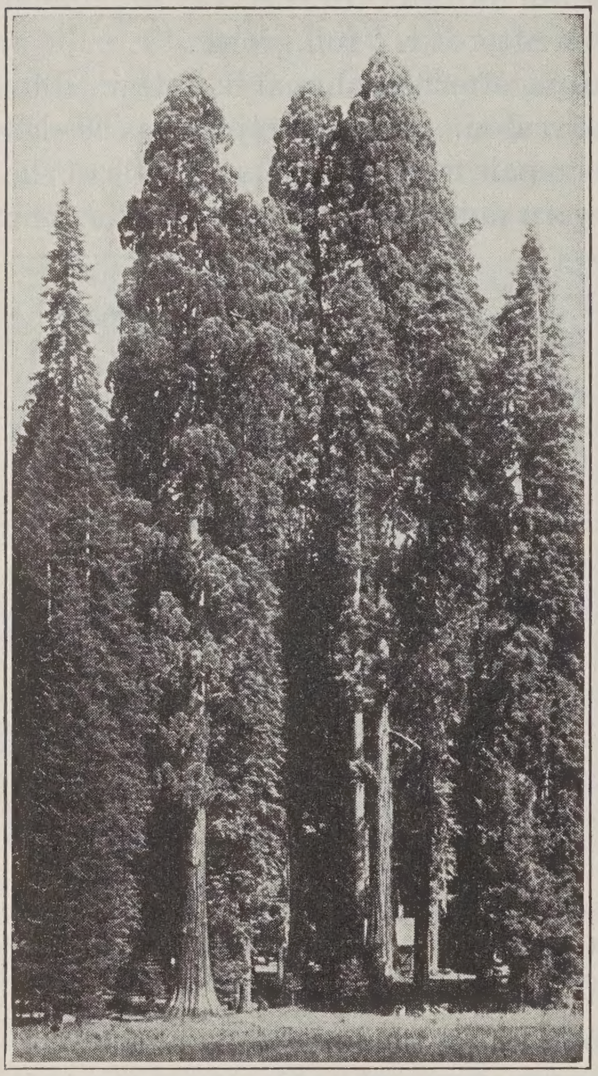


Courtesy Brooklyn Botanic Garden

FIG. 174. The carrot plant is a biennial. Of what use is the large root to the carrot plant? Of what use is the root to man?

What other changes may take place during growth in an animal? As the cells of an animal increase in number and the organism grows larger, it goes through regular changes which are spoken of as its development. The head of a baby is large in proportion to the body; since the body grows faster than the head, the proportions change.

In some animals the changes during growth are much more striking. As you may know, the egg of the butterfly develops into a caterpillar; the egg of the frog forms the tadpole. In these cases, where the animal passes through stages which bear little or no resemblance to the parent, its development is called a *metamorphosis* (met-a-mor′pho-sis). But metamorphosis is not the rule.



Courtesy *U. S. Dept. of Interior*

Fig. 175. Can you see the house at the foot of these giant redwoods? If it is 20 feet high, about how tall are the trees? Where are the growing regions in these trees which enable them to grow taller?

How long do the cells of plants continue to divide? You know that in an animal most of the growth in its youth is caused by an increase in the number of cells; but that normally most of the cells stop dividing at a certain time and the animal stops growing. Certain flowering plants, like the morning glory, corn, and sweet pea, reach a certain size, stop growing, and die at the end of the season. They are called *annuals.* Other plants, *biennials* (by-en′nee-als), live for two years. They grow to a certain size, and as the cold weather approaches they send all their manufactured food into the roots to be stored. This stored food enables the plant to produce a few leaves the second year, but it is used chiefly to produce flowers and seeds.

There are many *perennial* plants such as trees and shrubs which live for many years. They retain their power of growth until the very end. In the case of some, such as the giant redwoods (sequoias) of our western coast and the gnarled cypress trees of Mexico, there seems to be no limit to their size. They go right on growing, although slowly, until they die; and death seems to be postponed almost indefinitely.

In all perennials the great majority of cells stop dividing; in fact many of them die. But there is always an actively growing region near the tip of every twig and every rootlet, which makes for increase in length, and just under the bark, which makes for increase in thickness. The tree becomes thicker very slowly but it grows taller quite noticeably. In parts of the world where there are distinct seasons growth ceases during the winter. The cells of the stem tip are then protected by heavy scales. This is known as a *terminal bud.* Along the sides of the stem are *lateral* buds containing cells which can grow into stems and leaves. Some buds produce flowers; sometimes a bud may produce both flowers and leaves. Thus, growth in plants differs in many ways from growth in animals. *Exercises 4, 5, 6, 7.*

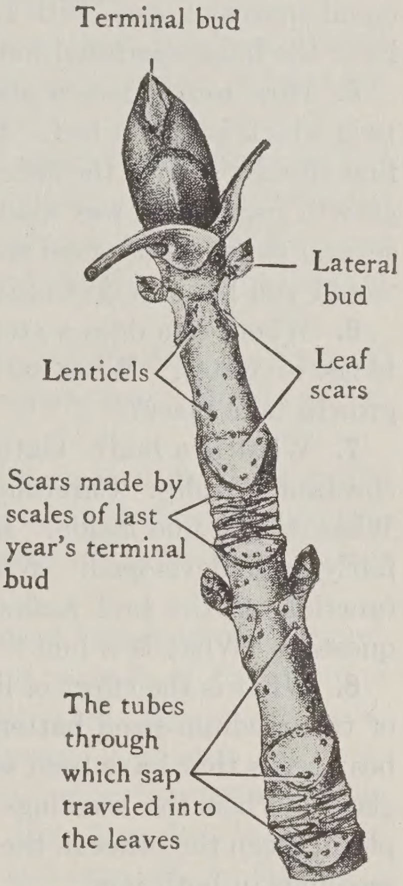

Terminal bud
Lateral bud
Lenticels
Leaf scars
Scars made by scales of last year's terminal bud
The tubes through which sap traveled into the leaves

FIG. 176. At what point would this stem grow longer if it were supplied with water and other food? How much did this stem increase in length in one year?

Exercises

1. How does the growth of crystals differ from the growth of living things? Dissolve as much copper sulphate as possible in hot water. Pour the solution into petri dishes and allow it to stand undisturbed. Examine each day for several days.

2. How much of bone, by weight, is intercellular; how much is cellular? Obtain two bones of about equal weight. Burn one bone to remove all of the cellular material. It may take several hours to do this. Allow the bone to cool and weigh it. Soak the other bone in 25% hydrochloric acid for a few days to remove the intercellular material. Then weigh it. Which weighs more, the cellular material or the intercellular?

3. Of what advantage is cell division to a cell? Fasten two books of the same size together with an elastic. Measure the outside surface. Now separate the books and measure the surface of each. How do their combined surfaces compare with the original? Since the cell absorbs food through its cell membrane, how does division help it?

4. Where is the growing region of the root of the pea seedling? Germinate some pea seeds in a dish containing moist sawdust or blotting paper. When the roots are about one half inch long, mark off about eight equal spaces on each with India ink. Observe for about a week. Where have the lines separated most? What does this indicate?

5. How much does a stem grow in length in one year? Examine a twig which is not in leaf. Measure it from the large terminal bud to the first circular scar on the twig. This scar marks the place where the season's growth began. It was made by last year's terminal bud. Do this with several twigs of the same species. Are all the distances the same? What would you have to do to make sure that your results were accurate?

6. Where else does a stem have growing regions? Place some willow twigs in water. What structures grow from the twigs? Where does growth take place?

7. What is a bud? Gather some twigs with large buds, like the horse chestnut or tulip. Carefully remove the outer leaves (scales) of the bud. What do you find inside? In the same way, examine flower buds that are fairly well developed. What do you find in this case? What is the function of the bud scales? Write a short paragraph to answer the question "What is a bud?"

8. What is the effect of light on the growth of a plant? Line the sides of two medium-sized battery jars with wet blotting paper. Place some bean seeds that have been soaked for 24 hours between the paper and the glass. When the seedlings are well developed, place one jar in a dark place; keep the other in the sunlight. Keep a record of the growth of the seedlings in both jars.

Problems for Classroom Discussion

1. After swallowing a large animal a boa constrictor is naturally greatly increased in size. Why is this not considered growth?

2. Would a cubic inch of skin from a cow contain more cells than a cubic inch of skin from a calf? Explain.

3. Would a cubic inch of muscle from a man contain more cells than a cubic inch of muscle from a baby? Explain.

4. Would you get the best carrots at the end of the first or second year? Why?

5. If you want a good flower garden will you plant annuals, biennials, or perennials?

6. If you cut off the lower branches of a tree, at what level would you expect to find the stumps each year? Explain.

7. *Summary.* See whether you can write the answer to each paragraph title in one short sentence. Now check those paragraphs that you think are most necessary in order to obtain an answer to the question "How do living things grow?"

Activities for the Junior Biologist

1. Your text says that the division of the nucleus is a complicated process. It is called mitosis. Look up a description of this process and make models to illustrate it.

2. Measure the annual growth in length of several twigs from each of several kinds of trees. Where did growth take place? How much did the twig grow? What differences do you note between the twigs of the same tree? Does there seem to be a difference in the rate of growth of twigs of different species?

3. Ask the class to choose a secretary to write to the Sequoia National Park, California, for information about the sequoia tree. Have a report written.

4. Gather frogs' eggs in the early spring. Place them in an aquarium containing plants, but no fish. Observe the growth of the eggs into tadpoles. Prepare a class exhibit of preserved specimens showing each stage in the life history of the frog.

5. If you have the opportunity to perform a long-continued experiment, raise a generation of moths. Hunt for cocoons of the Cecropia moth in the fall, winter, or early spring. Keep notes. Keep the cocoons in a cold place in a large box covered with a screen. Cut open one of the cocoons to see what it contains. Note the date when the moths emerge. How does the moth emerge from its cocoon? How long does this process take? Upon emerging, the moths will mate and eggs will be laid. Use the leaves of the wild black cherry for food. Keep a record of the growth of the larvae. Observe the formation of the cocoon. Make an exhibit of actual specimens to show the life history of this moth.

6. Does temperature affect the rate of growth of young seedlings? Devise and perform an experiment to answer this question. Keep a careful record of your results.

7. What other factors might have an influence on the growth of plants? What experiments could you perform to test your judgment?

Problem 2. How Else Do Animals and Plants Use Food?

Plants and animals do work. Throughout the life of the organism, much of the food it gets is used for a purpose other than growth. To understand this use of food, you will have to understand what is meant by *force.* Most of you use it correctly in daily speech; you think of a force as a push or a pull. So does the scientist. You are well acquainted with some of the examples of force in you. When you walk you exert pushes and pulls; force enters into your breathing because your chest moves. You will learn later how pushes and pulls enter into many internal activities. And this applies not only to animals but to plants as well.

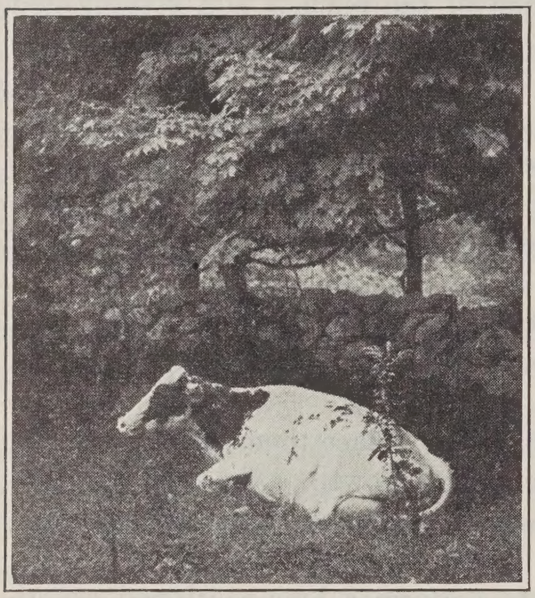


Photo by H. Schneider and J. Schwartz

FIG. 177. What parts of this resting cow are doing work? What work is being done by the tree and by the blades of grass?

When a force moves an object, the scientist says that *work* has been done. This is not the way the word is used in ordinary conversation. When you say "work" you usually refer to the things people do to earn a living or to the school activities in which you engage. The scientist uses the word in a different sense. If the object that is moved is light and is pushed or pulled a short distance he says that little work is done because little force is required. A great deal of work is done when the object is heavy (requires a large force) and is moved through a great distance.

Living things do work, in the scientific sense, just as machines do. Whenever animals and the tiny swimming plants move, they are using force to make an object change its position. Even when they stand still, living things move parts of themselves. The tentacles of little sea animals, the leaves that turn toward the sun, the hearts that beat, the muscles that contract — all engage in movement in which force is used. The movement of protoplasm in a cell means that pushes and pulls occur there on a tiny scale; that is, the cell is doing work. Thus biologists have noted that not only the whole organism does work, but each part of it does work, even the little bit of protoplasm within each cell.

The amount of work done is different for different organisms. In general, animals do more work than plants. Active animals, like dogs, do more work than inactive animals like sheep. And the same animal or plant does not do the same amount of work at all times. In winter, when its leaves are gone, the tree does little work. The animal which is *hibernating* (hy′ber-nat-ing — sleeping through the winter) does much less work than when it was actively hunting food. When you are asleep, you do relatively little work, too. *Exercises 1, 2.*

What makes work possible? Sometimes, as you know, you are able to do a great deal of work; at other times you find yourself able to do little. You may explain this by saying that you have little energy in the second case but had a great deal of energy in the first. You often say of a person who does much work that he is energetic. This is the scientific use of the word *energy,* for by energy scientists mean the capacity to do work.

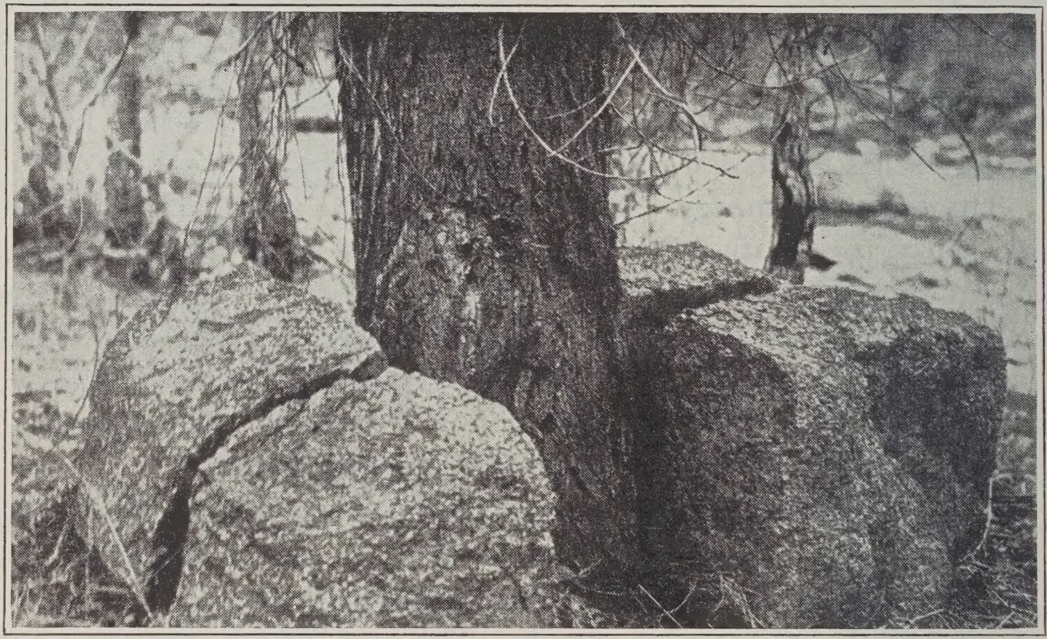
The forms of energy. In a simple machine like a steam engine it is easy to see that the engine cannot do work unless there is steam to push the pistons. You say, therefore, that steam has energy, the ability to do work. When the steam grows cooler and becomes water again, it can no longer push the pistons; that is, it can no longer do work; it has lost its energy. The scientist, therefore, calls the energy of the steam, *heat energy.*

There are other forms of energy besides heat energy. When the pistons and rods of an engine move they show *mechanical energy.* An electric motor has the ability to do work because of the presence of electricity or *electrical energy.* The coal which was used for making the steam had energy, too. This energy lies in its chemical make-up; for that reason it is called *chemical energy.* Another form of energy that you meet frequently is *light energy.* The sun and electric lights provide you with this form of energy as well as with heat energy. Man does not often use light energy for running machines but, as you have learned, light energy does an important job when it enters the green plant. Photosynthesis is dependent on the light energy of the sun. *Exercise 3.*

What forms of energy do living things show? Since your body, when you are in good health, has a temperature of 98.6° Fahrenheit, you certainly have heat energy. Investigation has shown that other animals have heat energy, also. So do plants, although in their case there is so little that only special instruments can detect it.

All kinds of animals have mechanical energy when they move. In plants, mechanical energy does not usually show itself so plainly. Yet, protoplasm streams in cells, twigs may bend, and roots push their way through the soil. Sometimes a tree cracks a cement pavement or splits a rock in two. Work is done in all cases, even though it is not done swiftly.

Electrical energy appears in all organisms; in tiny amounts in most of them, though in some there is enough to be readily detected. The electric eel and some other animals generate enough electrical energy to give a man a severe shock. Light energy is present, as you know, in fireflies and glowworms, in many deep sea fishes, and in Noctiluca, the protozoan that sometimes lights up the ocean at night. In general, however, light energy is rarely met with in living things. Living things also have chemical energy although it is not easily recognized.



Courtesy American Museum of Natural History

FIG. 178. Year after year the pieces of rock are pushed farther apart. Could you develop enough mechanical energy to push these rocks apart?

One form of energy may be changed into another. When you attach the electric toaster to the outlet, the toaster receives a supply of electrical energy which it changes into heat energy. In the electric bulb, the electrical energy is changed into light energy. These are two common examples of the way in which one form of energy is changed into another. If you were to trace the electrical energy back you might find that it was made by a dynamo that was turned by water held back by a dam. The mechanical energy of the powerful water flow was changed into electrical energy by the dynamo.

Another common change of energy takes place when something is burned. Both heat and light energy are produced. In this case the burning has changed the chemical energy of the burned substance into heat and light. Such substances as wood, coal, and oil may provide the chemical energy. *Exercises 4, 5, 6, 7.*

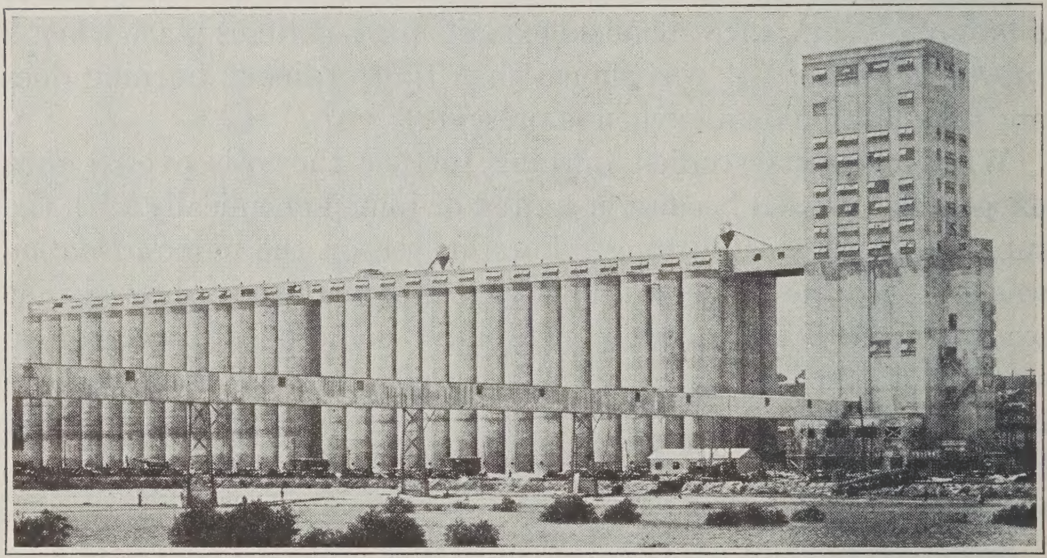
What is burning? It is interesting to note that it is only about a hundred years since chemists explained what takes place when a substance burns. It was shown then that ordinary burning does not take place unless oxygen is present.

When chemists studied burning further they discovered that oxygen was needed because it united or joined chemically with the substance that was burning. For this reason the name *oxidation* was given to the process of burning. Further study showed that oxidation did not always go on rapidly; sometimes it went on so slowly that no light energy was released; but, by using delicate instruments, chemists found that even slow oxidation released heat energy which had come from the chemical energy of the substance that was oxidized.

Since oxygen unites with the substance that is being oxidized, oxides are formed. These are compounds containing oxygen. If it is carbon that is oxidized the product of the oxidation is carbon dioxide (sometimes it is carbon monoxide). If it is hydrogen that unites with the oxygen, the product is hydrogen oxide, which is water. Phosphorus forms phosphorus pentoxide, and so on. This made it easy for the chemist to discover when oxidation was going on. He could test to find out whether or not heat was being given off and then he could look for oxides, too. By studying the oxides he could even learn what substances were being oxidized. *Exercises 8, 9, 10.*

What energy changes go on in living things? Since oxidation seems to be a way of obtaining heat energy from chemical energy scientists began to suspect that oxidation might be going on in plants and animals. To check this belief the substances given off by living things were studied. Among them were found oxides, chiefly carbon dioxide and water. This showed not only that oxidation goes on in living things but indicated what was being oxidized: namely, carbon and hydrogen. You know that all living things contain the nutrients, proteins, carbohydrates, and fats, all of which have in them both carbon and hydrogen. It is these nutrients that are oxidized.

Of course, the type of oxidation that goes on in living things is not the rapid type known as burning. Protoplasm would be killed by the high temperatures that burning produces. But the slow oxidation that takes place in you and in me, in every other animal and in every plant, is constantly supplying heat energy, which may then be changed into all the other kinds of energy.



Courtesy Union Pacific R.R.

Fig. 179. This huge grain elevator stores an enormous amount of chemical energy. Explain.

To supply this heat energy, it is necessary, of course, that the nutrients of the food have chemical energy stored within them. *Exercises 11, 12, 13.*

How does chemical energy get into the nutrients? The chemical energy of the nutrients must, in its turn, have come from some other form of energy. It is not difficult to find out what this other form of energy was if you think back to food getting in plants and animals. You will remember that plants take in air and water and manufacture carbohydrates; but that they cannot perform photosynthesis unless they have sunlight, or, as you have now learned to call it, light energy. This light energy is converted into chemical energy and is stored in the sugar or starch. If, later, the plant changes the sugar into fats or, by adding mineral substances, makes proteins, the chemical energy of the carbohydrate is passed on to the new substance manufactured. In fact, if assimilation takes place the energy is passed right along into the protoplasm itself. All of the chemical energy of the nutrients is the converted light energy from the sun.

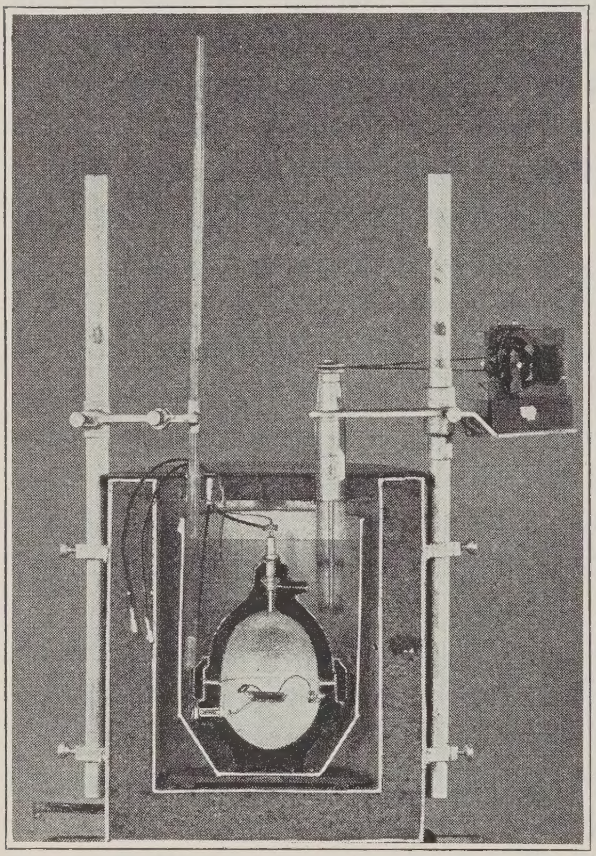
But the animal eats the plant or perhaps some other animal which had at one time fed on plant food. In either case it obtains nutrients the chemical energy of which has come from the same source — the light energy of the sun.

Energy and living things. Green plants, which can build up nutrients, are engaged in storing up the energy of the sun by transforming it into chemical energy. Animals cannot do this; they constantly use up the stored chemical energy by changing it to heat and other forms. In general, green plants are energy storers, animals are energy users; this is an important difference between them.

Of course, green plants are also energy users because they must oxidize nutrients to obtain energy. But the rate of oxidation in the green plant is usually far slower than in the animal.

How can scientists measure the energy of nutrients? If heat is applied to a kettle containing water the temperature of the water rises. If only a little heat is applied the temperature will rise very little. A burning match held under a kettle full of water will not make the water much warmer. More heat, obtained by burning a hundred matches, will have more effect. Scientists use this fact to arrive at a measure for heat.

They take a kilogram (2.2 pounds; a little more than a quart) of pure water and apply heat to it. When its temperature has gone up one degree centigrade, they say a single unit of heat has been added to the water. It is easy to measure the amount of heat that has been added by measuring the rise in temperature. If the temperature of the water goes up seven degrees, then seven units of heat have been added to a kilogram of water. If ten kilograms of water are used and the temperature goes up two degrees centigrade, then 20 units of heat have been added to the water (10 × 2). The name given to the heat unit is *Calorie* (kal'or-ee); so that it is proper to say 20 Calories were added to the water in the last case mentioned. This unit of heat may be used to measure the energy of nutrients because the amount of heat given off shows how much chemical energy was stored in the nutrient to begin with.



Courtesy Amer. Mus. Nat. Hist.

FIG. 180. Cross section of a calorimeter. Where is the food burned? Of what use is the long thermometer on the left? The electric motor on the shelf turns two paddle wheels in the water. Of what use are they? Why is the outside wall of the calorimeter so thick?

To find out how much heat is given off by a nutrient when it is oxidized, some of the pure nutrient is weighed so that the scientist knows exactly how much is going to be burned. He then places the nutrient inside a chamber in which the nutrient can be oxidized. Surrounding the chamber, so that it catches every bit of heat given off, is pure water, contained in a jacket. The outside of the jacket is covered with asbestos or some other material that holds heat in. The temperature of the water is taken before and after the oxidation. A typical example of the work of this instrument is as follows: A piece of bread is burned. This is not a pure nutrient, of course, but the scientist wants to find out how many Calories may be given off by a thick slice of white bread. After the bread has burned, the thermometer shows that the temperature of 11 kilograms of water has been raised 10 degrees centigrade by the oxidation. Then the scientist knows that a slice of white bread such as he used can release 110 Calories.

The instrument that is used is called a calorimeter (calor-im′e-ter). By its use, the heat values of nutrients and foods have been carefully measured. We now know exactly how much heat energy we may expect to get from the various nutrients and from most of the foods commonly eaten. You will make use of some of this information later on.

Exercises

1. When are you doing work? Observe yourself for a period of five minutes while engaged in some activity. How many instances of work can you list? Observe yourself at rest. Are you doing work? How?

2. How does steam do work? Pour an inch of water into a strong test tube. Cork it, but *not tightly*. Heat the water until it boils. What happens? Why? (**Caution:** Hold the test tube so that the corked mouth points toward the ceiling and away from any nearby person.)

3. What form of energy does a radiometer detect? Place the radiometer in the sunlight and in the dark. Is it the heat or the light energy of the sun which makes the vanes turn? How could you find out? What is shown by the turning of the vanes?

4. What energy change can be made by a wet cell? Make a wet electric cell by filling a small battery jar with dilute sulphuric acid (to be obtained from your teacher). Use copper wire to connect a copper plate to one pole of an electric bell or bulb and a zinc plate to the other. Now place the plates in the dilute acid. What happens? What does this show?

5. What energy change may take place when an electric current is passed through a wire? Fasten a silver or copper wire to the poles of an induction coil to which several dry cells are connected. Light a piece of paper with it when it gets red hot. What forms has energy taken in this experiment?

6. What energy changes take place when a generator is operated? Connect a generator to a bell, electric light, or small motor. Turn the coils of the generator by hand. What energy changes take place?

7. How can electrical energy be made to lift things? Wind several coils of insulated wire around a large iron nail. Connect the ends of the wire to a dry cell. Now try to lift tacks or iron filings with the large nail. What happens? What are the changes in the forms of energy?

8. Does the oxygen of the air support burning? Your teacher can provide you with air from which oxygen has been removed and to which practically nothing else has been added. Thrust a brightly burning taper into it. What happens? Why? How may your teacher have removed the oxygen?

9. When does the process of oxidation stop? Fasten a candle to a block of wood. Float the block in a pan of limewater. Light the candle.

Invert a jar over it so the mouth of the jar is under the limewater. Why does the candle go out? What substances are produced by the burning of a candle? Where do these substances go? Why does the limewater rise?

10. How can you find out whether a candle, like wood, contains carbon and hydrogen? Plan the experiment. Check with your classmates before performing it. Write an account of your work.

11. How can you show that oxidation is going on in your body? Breathe out for a few minutes through a tube into a small bottle containing some limewater. What do you note? Explain. Now shake a similar bottle of limewater so that it is well mixed with air. Why should this be done? What other evidence have you that oxidation is going on in your body?

12. At what rates do the nutrients unite with oxygen? Place each of the nutrients — starch, sugar, protein, and fat — in turn in an old spoon. Hold each of them in a Bunsen flame. Which of the nutrients burns most readily? Are any difficult to burn? Which can be used to supply the body with energy? Why? Try to burn some mineral matter. What happens?

13. Does oxidation go on in plants? Place a little moist blotting paper into one thermos bottle and the same amount of blotting paper moistened with formalin into a second. Half fill the first with soaked seeds; the second with seeds soaked in a weak formalin solution. (This kills the cells and prevents decay.) Lightly cover the peas with wads of absorbent cotton moistened with water and formalin solution respectively. Insert a thermometer through a hole in the cork in each bottle. The bulb must be well surrounded by peas. Read the thermometers and record. A day or two later when the living peas should be actively sprouting read the thermometers again. What conclusion can you draw? Why can you show oxidation in plants more readily with sprouting seeds than with other portions of the plant?

Problems for Classroom Discussion

1. Which does more work when swimming, the whale or the herring? Why?

2. A boy takes 10 minutes to pull a weight 100 feet. Another boy pulls the same weight for the same distance in half the time. Have the boys done the same amount of work? Explain.

3. What kinds of energy does a football player display?

4. Can you list examples of the display of energy by various living things? Try to draw up a long list.

5. Can you prepare several lists to show how one form of energy is changed into another and then into another, for use by man?

6. How do the various ways of extinguishing fires take into account the fact that burning requires oxygen?

7. Can you suggest a chemical explanation of the fact that substances like carbon dioxide and water (hydrogen oxide) cannot be made to burn?

8. Who would require more food, a lumberjack or a clerk? Why?

9. How is the electrical energy of the eel derived from the sun?

10. A certain piece of hot iron when plunged into half a kilogram of water raised the temperature of the water three degrees centigrade. How many Calories of heat were added to the water?

11. How many Calories of heat would have to be taken from a kilogram of water to lower its temperature from 75 degrees centigrade to 69 degrees centigrade?

12. *Summary.* You can summarize this problem in two parts. First explain energy and its relation to oxidation. Second, explain the relation of oxidation to living things. Which paragraphs discuss this second topic?

Activities for the Junior Biologist

1. Using man or another animal with which you are familiar, work out the path taken by the energy of the sunlight in reaching and being used by him. You might, for example, show how sunlight made a touchdown or wrote a poem. Could you construct a model or chart to show the paths of energy? (*Hint.* Yarns of various colors could lead from organism to organism. What would be their source?)

2. Report on the formation of coal. Note especially how energy came to be stored in the coal. Bulletin School Nature League, March, 1938.

3. Machines make it easier for man to do work. Demonstrate several simple machines, such as the pulley and the various types of levers.

4. You can make a simple working model of an electric generator with little more than some coils of wire mounted so that they rotate between the ends of a horseshoe magnet.

5. Plan a demonstration that would show the transformation of one form of energy into various other forms.

6. Look up and report to the class on solar engines.

7. Look up and report on the work of Priestley and Lavoisier.

8. Devise an experiment to show that the rate of oxidation is increased when the percentage of oxygen is increased.

9. What effect on the rate of oxidation in a cold-blooded animal is produced by the lowering of the temperature? The rate of breathing is an indication of the rate of oxidation; the faster the breathing the faster the rate of oxidation in the body and vice versa. Place a frog in a jar containing a small amount of water. Count the number of breaths it takes per minute. Now place the jar in a larger jar partly filled with water. Add ice to the water in the large jar. What is the effect of the lowered temperature on the rate of the frog's breathing? Add warm water to the large jar. What happens? Make a report to the class. If you regulate the temperature carefully you can obtain a complete set of figures for various temperatures. These will enable you to prepare a graph or curve. (Your mathematics teacher can help you if you do not know how to construct a graph.)

Problem 3. How Should Man Plan His Diet to Make the Wisest Use of His Food?

Why is it helpful to make a study of foods? You have just learned that foods serve two functions: they are used for assimilation and for the release of energy. But foods are combinations of several substances. Besides the nutrients (carbohydrates, proteins, and fats) they contain minerals, water, and some other substances. It is only the nutrients that can be used for oxidation; but proteins, fats, minerals, and water are used for assimilation.

Each food is different from every other food with regard to the substances which make it up. If you could buy a pound of protein or two cents' worth of calcium phosphate it would be easy to obtain what you need. Instead you buy flour and carrots and bread. With each purchase you take, by way of nutrients, water and minerals, whatever you happen to get. Therefore it is helpful to learn something about the composition of foods.

How do people get along without any knowledge of food composition? Many people know very little about the foods they eat. Until recently men of science could give them no help. In some instances people eat whatever is easy to get; more often they choose foods in accordance with customs learned from their parents; that is, they eat the food that everyone around them eats, cooked in ways taught by one generation to the next.

In most cases these diets seem to be fairly satisfactory. The reason for this is that often by unconscious trial and error over long periods of time people have succeeded in establishing eating habits which in general obey the rules of diet discovered by scientists. Sometimes, it is true, because of their ignorance, people fall ill of preventable diseases due to faulty diet. Much more frequently they manage to get along, although not in the best general health nor with the maximum amount of vigor. *Exercise 1.*

What general facts should everyone know about the composition of foods? For some years now scientists have been applying the food tests you learned as well as other more delicate tests to large numbers of foods. They have determined not only which substances are present but in what proportions they occur in all the common foods.

Of course, you cannot remember the composition of foods in more than a very general way. For more definite information you can always turn to the tables in this and other books containing information about foods. *Exercise 2.*

How much food do you need each day? You need a certain amount of food for assimilation; it is difficult to lay down definite rules about the amount, but it is small except during the period of active growth. Most of the food you eat goes into supplying energy. You already know that by means of a calorimeter it is possible to determine exactly how much energy can be obtained from a given amount of each nutrient. If, therefore, you could know how much energy you use up each day you could calculate how much food you need to supply it. It is not a particularly difficult task nowadays to measure the energy a person uses. Within the half century an apparatus was designed that made this measurement possible.

This apparatus measures the amount of heat indirectly. Since oxidation in the human body goes on deep within the billions of living cells there is no direct way of measuring the heat that is released. But it is possible to catch the products of oxidation (carbon dioxide and water), examine the other excretions, and take note of any changes of temperature either inside the body or outside in the air surrounding it. Complex calculations can then be made which will produce a fairly accurate statement of the oxidation rate and of the amount of heat energy released.

The energy requirements of persons vary greatly. It is known that they vary according to the sex, age, weight, and occupation. For many boys and girls the factor of occupation is of little importance, because they are attending school and have few other duties. Unusual activity in athletics would, of course, make a difference. *Exercise 3.*

COMPOSITION OF FOODS

Compiled from figures of Sherman, Rose, and others

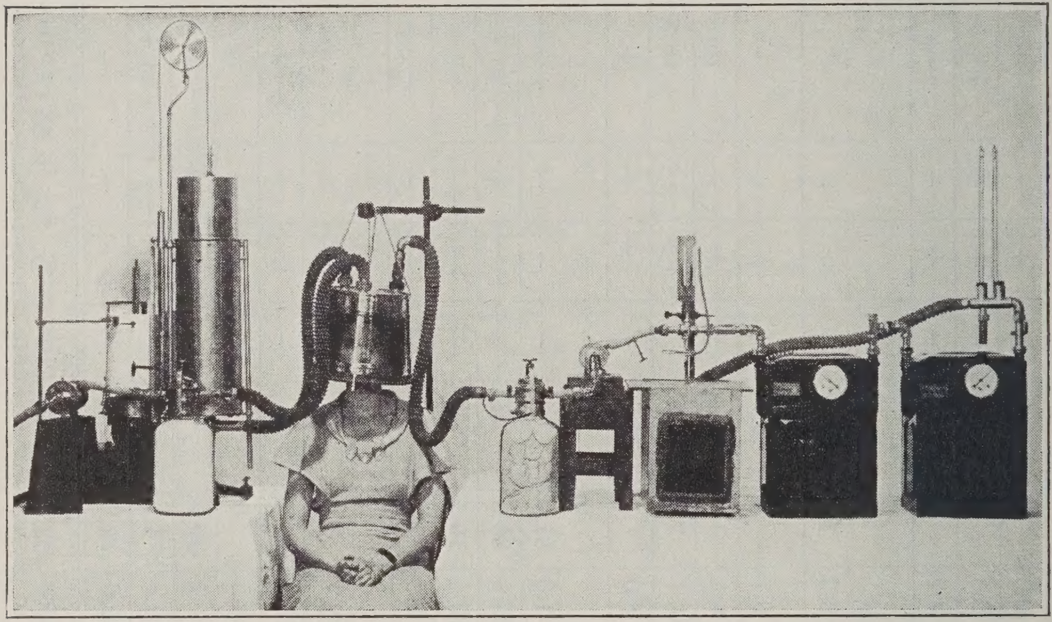
Food	Measure	Weight (*ounces*)	Calories	Per Cent Protein	Per Cent Fat	Per Cent Carbohydrate	Ca	P	Fe	A	B	C	G
Fruits & Nuts													
Apples, fresh	1 medium	6.0	80	.4	.5	14.2	–	–	–	+	+ to ++	++	++
Bananas	1 medium	5.5	100	1.2	.2	23.0	–	+	–	+ to ++	+ to ++	++	++
Grapefruit	½ large	10.0	100	0.5	.2	10.1	–	+	–	+	++	+++	++
Grapes	20 grapes	3.5	100	1.3	1.6	19.2	–	+	–	+	+	– to +	+
Oranges	1 medium	7.5	80	.8	.2	11.6	+	–	–	+	++	+++	++
Pears, fresh	1 medium	2.8	50	.7	.4	15.8	–	–	–	?	++	+	++
Peanuts, shelled	20 kernels	.6	100	25.8	38.6	24.4	+	++	+	+	++	?	+
Prunes, dried	4 medium	1.4	100	2.1	–	73.3	+	+	+	++	++	–	++
Vegetables													
Beans, kidney, dried	½ cup	3.5	347	20.0	1.8	55.2	++	+++	+++	+	++	?	+
Beans, string, fresh	¾ cup	3.5	42	2.4	.2	7.7	+	+	+	++	++	++	++
Cabbage, fresh	1 cup chopped	3.1	28	1.4	.2	5.3	+	+	–	+	++	+++	++
Carrots, fresh	¾ cup	3.5	45	1.2	.3	9.3	+	+	–	+++	++	++	++
Cauliflower	1 cup chopped	3.5	32	2.4	.2	4.9	++	+	–	+	++	+	++
Lettuce	3 large leaves	1.9	10	1.2	.2	2.9	+	+	+	+ to ++	++	++	++
Onions, fresh	1 medium	2.2	30	1.6	.3	9.9	+	+	–	– to +	+	++	+
Peas, fresh	¾ cup	3.5	100	6.7	.4	17.7	–	+	+	++	++	+++	++
Potatoes, sweet	1 medium	7.1	200	1.8	.7	27.9	–	+	–	+++	++	++	+

Potatoes, white	1 medium	5.3	100	2.0	.1	19.1	–	+	+	+	++	++	+
Spinach, fresh	1 cup	8.0	55	2.3	.3	3.2	+	+	+	+++	+	++	++
Tomatoes, canned	⅔ cup	5.0	35	1.2	.2	4.0	–	+	–	++	++	+++	+
Cereals													
Bread, white, with water	2 slices	1.4	100	9.2	1.3	53.1	+	+	–	?	+	–	?
Bread, whole wheat, with water	1 slice	1.0	74	9.7	.9	49.7	+	+	+	+	+++	?	+
Cornmeal	1 cup	5.0	504	9.2	1.9	75.4	–	+	–	– to +	+	–	?
Oatmeal	1 cup	2.6	298	16.1	7.2	67.5	+	++	++	– to +	++	–	+
Rice, brown	½ cup	3.5	351	8.0	.3	79.0	+	++	+	+	++	–	+
Dairy Products													
Butter	1 square	.3	50	1.0	81.0		–	–	–	+++	–	–	–
Cheese, American	1 tablespoon	.3	33	28.8	35.9	.3	+++	+++	+	++ to +++	?	?	+
Eggs, whole	1 egg	1.6	68	13.4	10.5		+	++	++	+++	+ to ++	–?	+++
Milk, whole	1 cup	8.5	170	3.3	4.0	5.0	++	+	–	+++	++	+ (Variable)	+++
Meats & Fish													
Beef, round	2½ × 2½ × ¾″	3.5	156	21.3	7.9		–	++	+	+	++	– to +	++
Bacon, smoked	4 slices	1.4	250	10.5	64.8		–	+	+	– to +	+ to ++	?	++
Flounder, fresh	1 small	16.0	282	14.2	.6		–	+	–	– to +	+	?	+
Lamb chops, broiled	2 chops, lean	2.4	244	21.7	29.9		–	++	++	– to +	++	?	++
Liver, beef	3 × 3 × ¾″	4.0	150	20.4	4.5	1.7	–	++	+++	++ to +++	++	+	+++
Salmon, canned	¾ cup	3.5	196	22.0	12.8		+	++	+	+	?	?	++

+, contains the mineral or vitamin; ++, a good source of the substance; +++, an excellent source of the substance; –, no appreciable amount of the substance; ?, doubt as to presence or absolute amount of the substance.

Since everyone's energy requirements can be calculated and since the amount of energy supplied by the common foods is known you could work out roughly how much food you should eat daily as a source of energy.

Of how much importance is it to calculate the number of Calories in a meal? When calorimeters were first used the enthusiasm of dietitians (people who study diets) led some of them to urge the housewife to study these tables so that she might plan her meals scientifically. But it was soon discovered that this was a difficult task and not at all necessary for the ordinary person. Normally, a person gets the right amount of Calories by following his appetite. However, this does not mean that information about Calories is useless. In planning meals for babies and for people who are not well or who are not normal in weight, constant use of the tables is desirable.

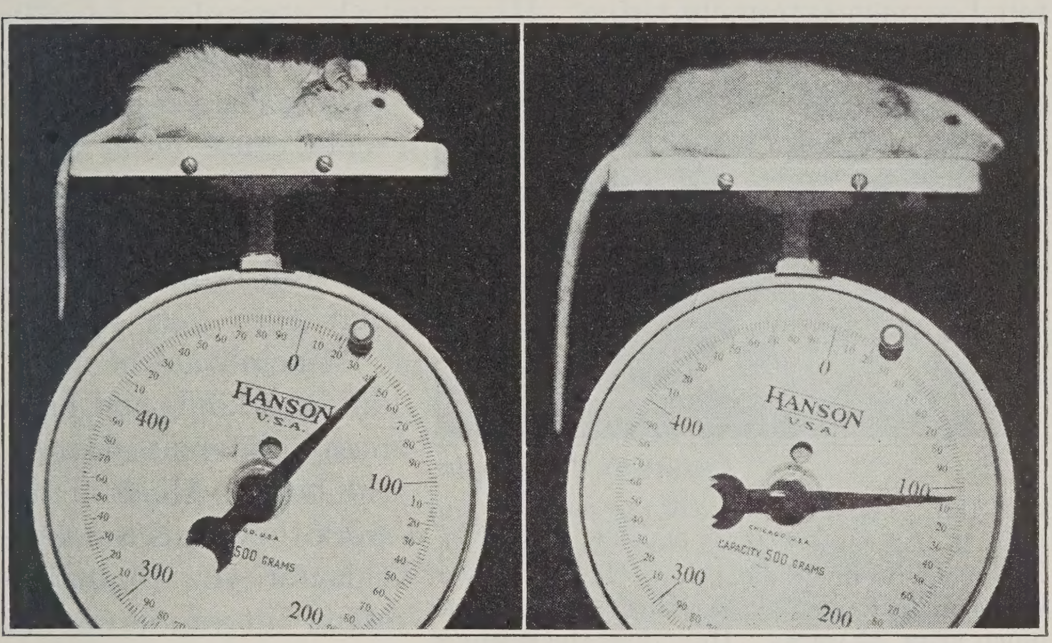


Courtesy Carnegie Nutrition Laboratory, Boston, Massachusetts

FIG. 181. Note all the apparatus used to measure the output of energy as shown in this picture. If the girl were exercising, what effect would this have on the amount of carbon dioxide breathed out? Why?

What important facts must you know to plan your meals wisely? You know that proteins and fats are used both for assimilation and for oxidation while the carbohydrates are used only for releasing energy. For that reason you would, of course, include protein and a little fat in every diet. Since assimilation goes on much more rapidly during active growth you would give comparatively larger amounts of protein to a young person.

But there is something else you must keep in mind about proteins: there are many kinds of proteins and the proteins in animal foods are generally like your body proteins. The proteins in plants, on the other hand, are rather different. In choosing foods for their protein, therefore, you would, under normal conditions, select some animal food and not depend entirely on plant foods rich in this nutrient.

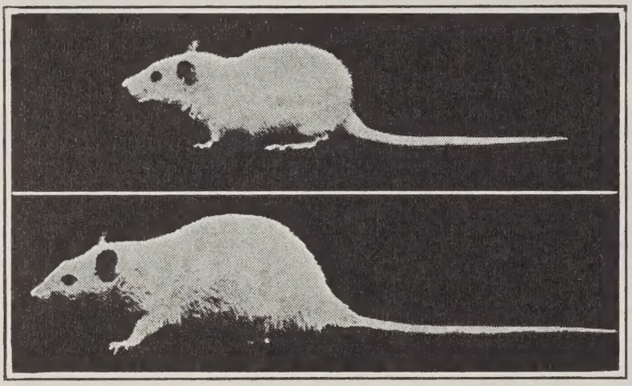


Courtesy Joseph G. Coffin, General Baking Co.

FIG. 182. The scientist learns many facts about diet by performing experiments. What is the reason for having two rats?

You already know that in most cases you depend on carbohydrates and fats for your energy, and not on protein. Fats provide more than twice as much energy as sugar and starch. Proteins, if they are used for oxidation, give somewhat more than carbohydrates. However, although fats give most energy it is not wise to use large amounts of fat. The body does not deal with them as successfully as with other nutrients. Alcohol provides large amounts of energy for a short time but it also reduces efficiency. In any but very small amounts it acts as a poison. When energy is needed immediately, there is no nutrient so satisfactory as sugar. Lumps of sugar and bars of chocolate are often given to football players before they go on the gridiron. *Exercise 4.*

Fats and carbohydrates have other uses in the body. They can be converted into body fat which is stored under the skin, in the muscles, and next to internal organs. Some fat tissue is necessary to keep you warm and in an emergency it may prove very useful. When a person does not eat he can draw on this body fat and change it back into substances which can be oxidized for giving energy. But to keep on storing fat (or anything else, for that matter) is useless. And when the extra material must be carried on one's back at all times wherever one may go, it is not only useless but becomes extremely tiring. However, when people, especially young people, are overweight there is generally some cause other than the eating of too much fat or carbohydrate, as you will learn in a later unit.



Courtesy U. S. Dept. of Agr.

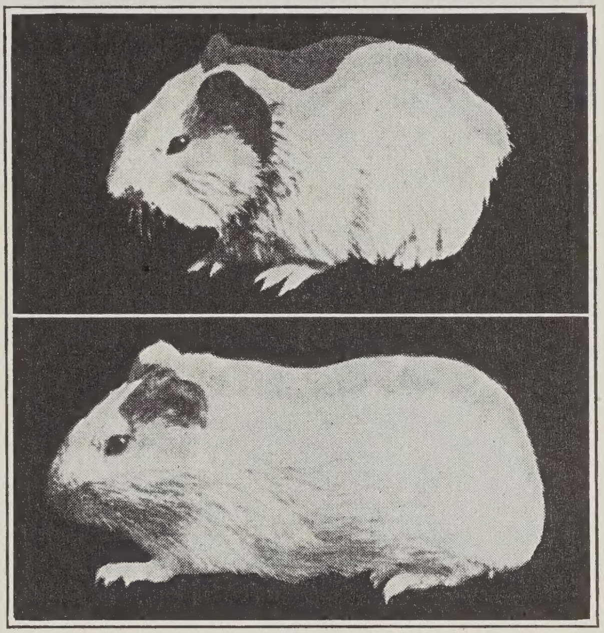
FIG. 183. These rats were of the same sex and born in the same litter. One was given too little calcium in its diet; the other was given sufficient calcium; it weighed $2\frac{1}{3}$ times as much after 22 weeks. How does the scientist know that calcium is necessary in the diet?

Minerals are of many different kinds and have many different uses in the body. Much of the work they do is too difficult for you to understand but you have read that certain minerals are necessary for assimilation. And you may know that calcium and phosphorus compounds are needed for making bones and teeth. Iron compounds are needed for making red blood cells. The actual amount needed may be very small. But minerals are essential; man cannot live without them.

Water is still another substance needed by the body. To begin with, it helps in assimilation. Then, too, it helps in dissolving substances so that they can move around by the process of osmosis. You will read more about that later on. You need a considerable amount of water each day, not less than two quarts or eight tumblerfuls. But it is not necessary for you to study the table to figure out how you can obtain this substance from solid foods because the easiest way is to drink water or other liquids. *Exercise 5.*

Foods contain proteins, carbohydrates, fats, minerals, and water; but they contain other useful substances too. They have minute amounts of many different compounds which add flavor. These add to your enjoyment of food. And plant foods have more or less cellulose and woody substances making up the walls of each cell. Potato skins and celery are made up almost entirely of such materials. You often eat them and while you obtain no nourishment from them they are of considerable importance to you. These substances are called *roughage.* A certain amount of roughage is valuable for making the intestines push the food along. You will understand this better when you have studied digestion.

But besides the flavoring and roughage, foods contain still other compounds which cannot be used directly for making protoplasm or for oxidation. Yet they are necessary to you. These substances were discovered in the course of experiments on diseases which had puzzled people for centuries. There were mysterious outbreaks of disease which seemed to have something to do with diet. Only within the last fifty years have scientists definitely cleared up these mysteries. At the same time they discovered facts which have revolutionized our ideas of diet.

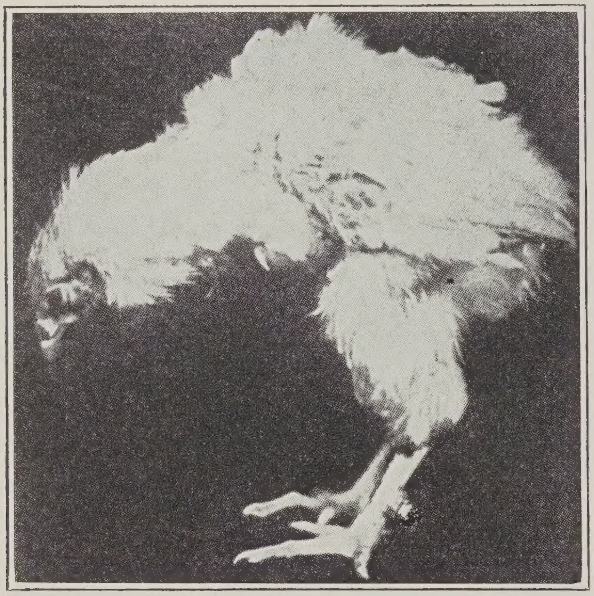


Courtesy U. S. Dept. of Agr.

FIG. 184. The rough fur and crouched position due to sore joints show scurvy in the smaller guinea pig.

What serious diseases were long ago suspected of being caused by improper diet? Away back in the dark ages men told of a dread disease which sooner or later attacked all sailors on long voyages. Their muscles ached, they became weaker and weaker, blood flowed from their noses; often they died. The disease was called *scurvy.* Whether they were poisoned by their food which consisted principally of salt fish and dry crackers, or grew sick from long exposure to the sea air no one knew. It was noted in England in the eighteenth century that if sailors drank the juice of lemons or limes, they did not suffer from scurvy. The reason was not known. But to prevent further outbreaks of the disease a law was passed in England more than a century ago requiring that a supply of lemons or limes be taken on long voyages.

Somewhat later the Japanese had similar disastrous experiences with another disease, outbreaks of which occurred in their navy in the nineteenth century. This disease was not new either; it had long been known in China, Japan, and other eastern countries; it is called beriberi (ber′ree-ber′-ree). It, too, results in exhaustion and eventually in death, but instead of bleeding there is numbness and paralysis.



Courtesy Illinois Agr. Expt. Sta.

Fig. 185. This chicken is suffering from polyneuritis, a disease much like beriberi in man. How could it be cured?

The diet of these sailors was largely polished rice, the kind of rice you ordinarily eat. Thinking that, as in the case of scurvy in Europe, the disease might be caused by a faulty diet, the officials of the Japanese navy, about 1880, ordered that other foods be provided the men in addition to polished rice. Very soon after that beriberi outbreaks became less frequent. Just what was wrong with the original diet no one knew. The government officials were content, since they had hit on a better diet; but scientists were not satisfied; their curiosity was aroused. *Exercise 6*.

How did scientific experiments clear up the mystery of beriberi? Some years after the new diet had been ordered and its good results had been proved a Dutch scientist by the name of Eijkman (Ike′-man) became interested in the cause of beriberi. He was stationed in one of the Dutch colonies in the East Indies where he saw daily the hundreds of sufferers in the beriberi hospital. He had noticed that chickens living on a diet of polished rice showed the same effects as the patients. He used chickens, therefore, in a carefully planned experiment. First, he fed many of the birds on a diet consisting only of polished rice. They developed a disease very much like beriberi. Then he divided his birds into two groups; with half he continued the diet of polished rice; to the other half he gave not only the polished rice but also the "polishings" or coatings of the rice which are removed when the rice goes through the mill.

Shortly after they had received the rice coatings this group of chickens recovered from the disease. The other group died. Eijkman concluded that there was something in the skin covering the grain that prevented the disease. When he ordered the natives to eat the coatings of the rice they, too, recovered from beriberi.

Other biologists studied the chemical make-up of the rice polishings in an attempt to find out what substance in them prevented beriberi. In 1911 Casimir Funk, a Polish biologist, extracted the substance and called it a "vitamine." Long-continued investigations have enabled scientists to extract it in its pure state. It is now called *vitamin B* (vyte′a-min).

What other experiments showed that vitamins existed? At about this same time other scientists made another discovery in the course of nutrition experiments on rats. They had prepared the meals carefully, giving the animals measured amounts of pure carbohydrates, proteins, fats, minerals, and water. By using the prepared substances instead of ordinary foods they were able to control the amounts more accurately. To their astonishment the rats developed an eye disease, sickened, and died.

The experiment was repeated but this time as soon as the rats became sick some of them were given a few drops of raw milk each day in addition to the diet of pure nutrients, minerals, and water. These rats regained their health and remained normal. It was plain that rats needed something more than proteins, fats, carbohydrates, minerals, and water, if they were to remain alive. Although the scientists did not know what that substance was, the experiment showed that it was contained in milk. Since small amounts of milk were given, it was apparent that the substance was needed in small amounts only.

Since the substance could not be separated from milk it was called a vitamin and given the name *vitamin A* to distinguish it from the vitamin in rice polishings which was now called vitamin B.

In the meantime other scientists had discovered by experiment that orange, tomato, lemon, and lime juice contain a different vitamin, one which prevents scurvy. This was called *vitamin C.*

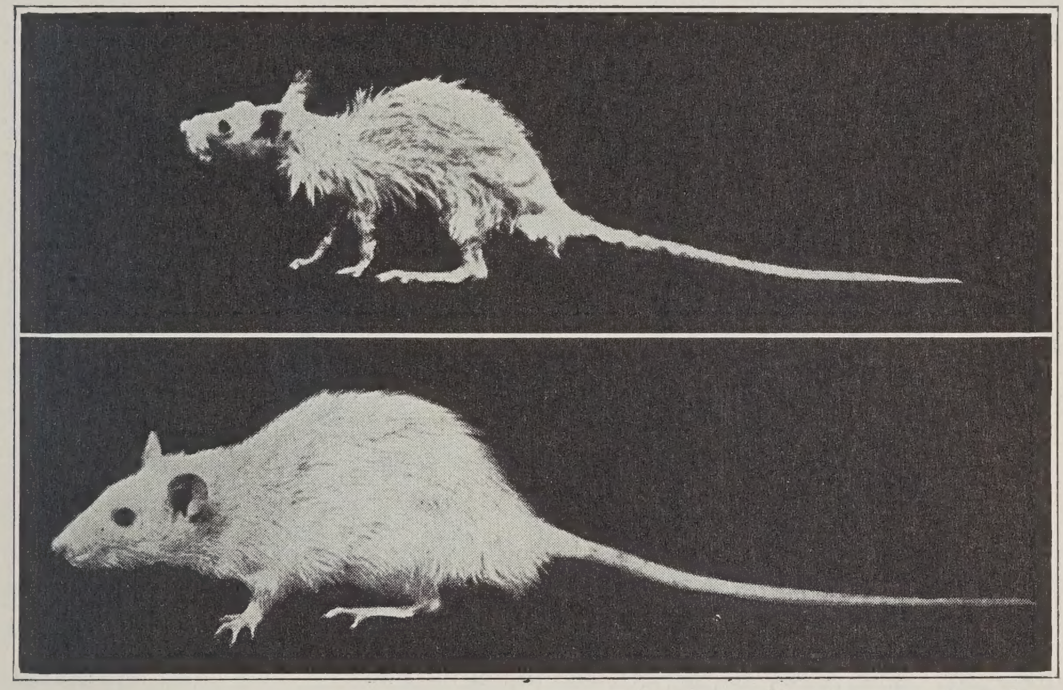
How can a scientist determine whether a food contains a vitamin? Until recently, when the biologist wanted to find out whether any food other than milk contained the vitamin that prevents the eye disease, he was forced to perform a biological test. First, he put healthy young white rats on a special diet which it was known from experience would lead them to develop the eye disease. When all of them were sick he added a small amount of one particular food to the diets of only half of them. If after a period of time the white rats getting this food recovered from the eye disease and the others did not, it was clear that the food contained vitamin A, the vitamin that prevents or cures the eye disease.

By means of these experiments vitamin A was found to be present in such foods as the yolk of eggs, spinach, and raw carrots. By similar experiments vitamin C was found not only in orange and tomato juice but in many leafy vegetables such as lettuce and cabbage and spinach. These foods do not all contain the vitamin in the same amounts. The scientist could tell roughly how much vitamin there was in any food by using larger and smaller amounts of the food in his experiment.

Recently, satisfactory chemical tests have been discovered for some of the vitamins. Such a vitamin can be discovered in a food, therefore, in somewhat the same way that a nutrient is.

How has our knowledge of vitamins been extended in recent years? There is another disease, *pellagra* (pel-lah′gra), which doctors soon suspected might be due to lack of some vitamin. It is a disease which often attacks people in institutions, such as prisons, orphan asylums, and others, where food often must be provided at a very low cost. This disease also is now under control since it was discovered that it is caused in large measure by the lack of a vitamin which is known as vitamin G or B_2. This vitamin is found in the same foods as vitamin B and for some time scientists thought it was identical with it. The terms B_1 and B_2 are now used.

More important than the discovery of vitamin G was the earlier discovery of vitamin D. It has been known for a long time that mineral compounds of calcium and phosphorus are needed for giving strength and rigidity to the bones and teeth. You have learned that foods containing these minerals should form part of the diet of every baby and of every growing boy or girl. But only recently was it found that these minerals cannot be used unless vitamin D is present. Without a sufficient amount of vitamin D in the body, the minerals are lost to the body. The child develops the condition known as *rickets*. Bones and teeth remain soft. Halibut-liver oil and cod-liver oil are the best sources of vitamin D and are now given to prevent rickets.

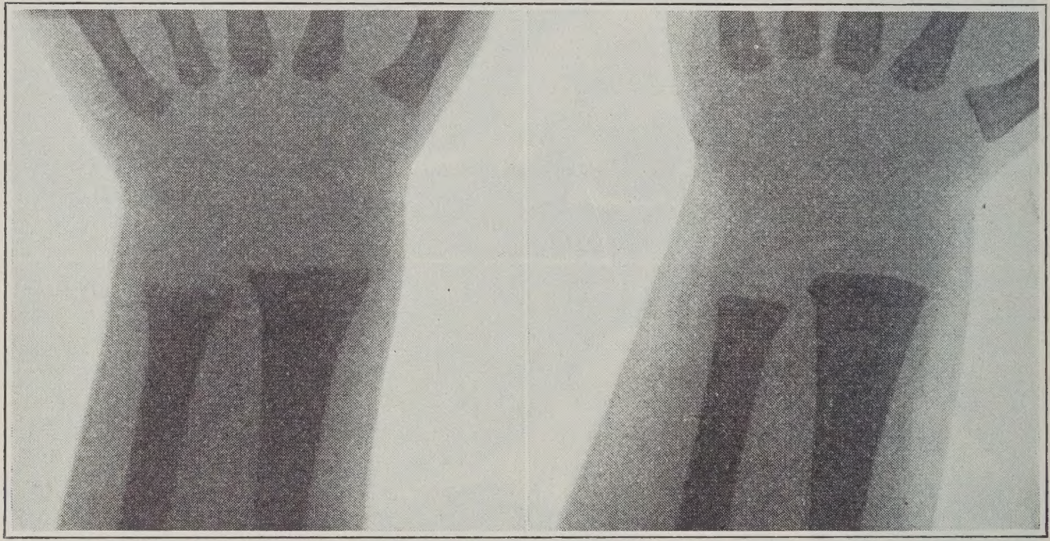


Courtesy United States Department of Agriculture

FIG. 186. This rat had been fed a diet lacking vitamin G. After six weeks of receiving food rich in vitamin G its weight increased from 63 grams to 169 grams. Does the biologist use only two rats in his experiments? Explain.

After the use of cod-liver oil had been established, another interesting fact was discovered about vitamin D. Children who play out of doors, especially in summer, do not need cod-liver oil. The reason for this is that the ultraviolet rays of the sun shining directly on the skin cause it to develop vitamin D. The beneficial action of these rays cannot be obtained indoors unless a special quartz glass is used because ordinary glass blocks their passage. Instead of putting the child in the sun, some foods which lack the vitamin may be placed in the path of the rays; this is called *irradiation.* Not all irradiation of foods is successful; ordinarily, such foods should not take the place of the fish liver oils. Cream contains fairly large amounts of vitamin D, but there is very little in skim milk. Sometimes irradiated yeast is fed to cows, which then produce milk with more vitamin D.

Vitamin E, which helps in the reproduction of rats, has been found in cotton, wheat, and other seeds. New vitamins are steadily being added to our list. Good newspapers carry reports of discoveries as they are made. While some scientists are looking for new vitamins, others are busy trying to learn what a vitamin really is. The exact chemical make-up of vitamins A, C, and B seems to have been established. Such patient research and so many experiments are necessary, that it is said that a shipload of the polishings of rice and a whole lakeful of water were used up in the preparation of a small amount of vitamin B_1.

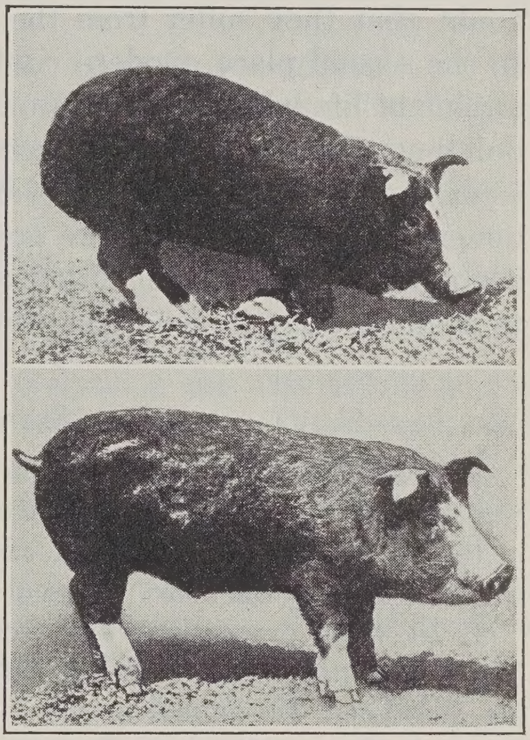


Courtesy Joseph G. Coffin, General Baking Co.

FIG. 187. The X ray to the left was taken on Feb. 3. This child had a bad case of rickets as shown by the fuzzy edge of the two bones in the arm. Treatment was begun. The second X ray was taken June 25. What difference can you see in the ends of the arm bones?

Of what importance are vitamins to you and me? It is easy to see that children need vitamin D during the early years while the bones and teeth are developing. But when it comes to vitamins B and C and G, their need is not so evident. Since you and I need only small amounts of these vitamins to save us from beriberi or scurvy or pellagra, we are not likely to suffer from one of these *deficiency diseases.* In any normal varied diet a trace of these vitamins is almost sure to appear. But if you choose your food without any thought of the vitamins it may contain, you are likely to be below par in one way or another. To keep in good condition, to resist disease, to have endurance and the power of recuperation, you need vitamins and you need a steady supply.

It has sometimes been asked whether it is possible to take in too much of a vitamin. This may be true of vitamin D; good authorities are still in doubt. It is not true of vitamin A, for apparently it can be stored for future need.



Courtesy Wisconsin Agr. Expt. Sta.

FIG. 188. Above is a pig suffering from rickets. Below is the same pig after small daily doses of cod-liver oil. What did the oil supply?

How may food lose some of its vitamins? Vitamins are chemical compounds which tend to change when exposed to dryness or light or extremes of temperature. Vitamin A, the vitamin of butter and yellow vegetables, is resistant to heat but is destroyed by exposure to air. Vitamin C can stand high temperatures under certain conditions only. If the food is heated while exposed to the air (oxygen) the vitamin is destroyed. In canning tomatoes, if heat is applied after the food is in a tightly sealed can very little of the precious vitamin C is lost. The acidity of the tomatoes seems to make the vitamin more heat resistant too. Therefore, properly canned tomatoes are a good substitute for fresh oranges. However, vitamin C is so sensitive to light that during the process of milking into open pails, during pasteurization, and particularly during the distribution of the milk in glass bottles it is almost entirely lost. Vitamin B seems to be more resistant than the others; foods containing vitamin B can be cooked without danger of destroying it. *Exercises 7, 8, 9.*

Why don't the other animals need to plan their diet? Other animals eat whatever their appetites dictate or whatever they chance to find; why should man select so carefully? In the first place, other animals would be better off if they ate more wisely. You have seen that they suffer from rickets at times. There is no doubt that they suffer from the lack of the other vitamins too. In the second place, modern civilization has produced many conditions of life which are harmful. Man lives in cities where high buildings and smoke cut off the sunlight. He often lives in large communities under great stress and strain. He has worries which undermine his health. There are dozens of ways in which his life is not a healthful one. For that reason he needs to do what he can to keep his body in good condition.

Exercises

1. What substances are present in each of several common foods? Use the standard food tests on the common foods contributed by members of the class. Prepare a table showing the results. Is your table better than the table in the book? Present reasons for your opinion.

2. In what proportions are proteins, carbohydrates, and minerals found in common foods? Using the table in the text answer the following questions: Do animal or plant foods contain larger percentages of protein? Do animal or plant foods contain larger percentages of carbohydrates? What foods contain large amounts of such important substances as iron and calcium? In general, what are the differences in composition between leafy vegetables and root vegetables? between vegetables and fruit?

3. The average Calories required per hour for each pound of a person's weight are:

In sleeping or lying awake	$\frac{1}{2}$ Calorie
Sitting	$\frac{2}{3}$ "
Typewriting	$\frac{9}{10}$ "
Standing	$\frac{3}{4}$ "
Walking at a moderate rate	$1\frac{1}{2}$ Calories
Active exercise	$1\frac{3}{4}$ "

If you weigh 120 pounds and sleep 9 hours, you would require for those 9 hours $120 \times \frac{1}{2} \times 9$ Calories. Decide about how many hours of the day you spend in each kind of activity and, considering your weight, calculate about how many Calories you need in 24 hours. Do not attempt to regulate your diet by these figures.

4. Organize several committees to study the evidence on the effects of alcohol on man. Why must you turn to scientists for trustworthy information?

5. (*a*) Considering all the facts you have just read and looking back to your table of fuel values, plan a day's meals which would satisfy the requirements.

(*b*) Plan three good, but different, meals for a second day.

6. Plan an experiment which would indicate that lemons and limes contain a substance that prevents scurvy.

7. Write out a complete list of the foods which you ate yesterday. Look at the table and state:

(*a*) Which of the vitamins did you get at least in small amounts? (Name the food which supplied each.)

(*b*) Of which vitamins did you get a large amount?

8. There are fads in diet as in everything else. By talking to your friends, see how many of these you can learn about. Discuss each one in class, in order to see, if you can, whether there is any scientific basis for it. In some cases it will be possible for you to test the truth of a statement by experiment.

9. Study the advertisements of foods in cars, magazines, etc. Copy them exactly and bring them to class for discussion. To what extent are they scientific? To what extent can you trust them?

Problems for Classroom Discussion

1. After consulting the table, make a list of ten foods that are useful sources of energy. Discuss their use under different conditions.

2. Besides the amount of food, what other factors must be taken into account in planning a good diet?

3. Name five foods which your physician might tell you to cut out of your diet if you had to reduce your weight. (**Caution:** No one should attempt to change his weight except under a physician's guidance.)

4. What truth is there in the statement that a piece of whole wheat bread will add less to the weight than a piece of white bread?

5. Consult your family and friends for other "rules" for losing weight. By reasoning and consulting your tables see whether you can find any scientific basis for their statements.

6. Write out three rules that you think should be followed to provide sufficient minerals in your diet.

7. If Eijkman had used only one group of chickens, what would their recovery from beriberi have proved? In what respects does his work illustrate the scientific method?

8. A biologist permitted scurvy to develop in a group of rats; he then fed half of them a few drops of milk and some raw tomatoes daily. The rats recovered. What can you conclude? Why did the other half remain sick?

9. List the foods, some of which should be included in the diet, to give you vitamin A; some for B, C, and D.

10. Turn back to the exercise in which you planned meals. Did you include the necessary vitamins in your three meals? In which foods? If not, revise your lists.

11. In what parts of the world do you suppose rickets is most prevalent? It would be interesting to verify your guess. How would you go about it?

12. When a baby's diet consists of pasteurized milk, what food should be added to the diet? Why?

13. Some people find tomatoes too acid, or sour, as they call it. To improve the taste they neutralize some of the acid by adding bicarbonate of soda when boiling the tomatoes. What is lost as a result?

14. Name five conditions likely to be found in towns or cities which might interfere with normal health.

15. *Summary.* You hear and read so many incorrect statements about food and diet that you must make sure that you have learned the important facts in this problem. What are they? Jot down the main headings under which you can gather together your facts.

16. *Unit Summary.* You can answer briefly the question, "How do animals and plants use their food?" But in connection with this subject what very important new ideas and information did you get? Look through each problem page by page and list the most important ideas.

Activities for the Junior Biologist

1. As you know, the diets of various peoples differ. Make a critical report on the diets of several national or religious groups, like the Eskimos, Arabs, Jews, Germans, Yankees, etc.

2. Milk is generally considered a good food for promoting growth. You can test this belief by using rats. Take a litter of rats about three weeks old and separate them into two groups. Keep one group on a diet of bread, a leafy vegetable, some meat, and water. Feed the second group the same diet, but with the addition of milk. Keep an accurate daily record of the weights of each group.*

---

* Do not cause animals pain or permit them to suffer. These experiments and others can be performed without harm to the experimental animals if you change the diet as soon as evidence of the effect of poor diet is obtained.

3. If your school has no charts showing the percentage composition of common foods, a group might make some. Draw the outline of common foods such as a rib roast, a fish, glass of milk, carrot, etc. By consulting the table show the proportion of protein, fat, carbohydrate, mineral, and water (including waste) in each food. Use different colors to indicate each nutrient.

Note. A few of you working together can determine the effect of the lack of vitamins upon certain animals. Report the results of your work to your class or club. If you have a school science paper, have your results published. There are a few points that all of these experiments have in common that you ought to know. You must choose animals that are in a good state of health. Wherever possible, the animals should be from the same litter and of the same sex. The animals are then divided into two equal groups. One group receives the diet lacking a particular vitamin while the other group gets the same diet plus the vitamin. You must remember that the conditions under which you keep the animals are as much a part of the experiment as the diet which you feed them. Therefore, keep them under normal conditions of temperature and in clean cages. Always keep an accurate record of your progress.

4. What is the effect of the lack of vitamin A upon rats? * Choose rats about three weeks old. Feed one group a diet consisting of the following:

Casein (pure protein)	20%
Lard (fat)	15%
Starch (carbohydrate)	56%
Yeast (for vitamin B)	5%
Salt mixture (for minerals)	4%

The salt mixture should be mixed with the other food. Your teacher will help you to get the chemicals you need to make the salt mixture.

Sodium chloride ($NaCl$)	5.19 gm.
Magnesium sulphate ($MgSO_4 \cdot 7H_2O$)	16.00 gm.
Sodium dihydrogen phosphate ($NaH_2PO_4 \cdot H_2O$)	10.41 gm.
Potassium hydrogen phosphate (K_2HPO_4)	28.62 gm.
Calcium lactate	39.00 gm.
Ferric lactate	3.54 gm.

The other group is fed butter instead of lard. When you have achieved your results, return both groups to a normal diet.

5. What is the effect of the lack of vitamin B upon pigeons? Using pigeons, repeat Eijkman's experiments. Shortly after the birds begin to show signs of the lack of the vitamin, return them to their normal diet.

---

* These diets are taken from *Adventures in Biology*, New York Association of Biology Teachers.

6. What is the effect of the lack of vitamin C upon guinea pigs? Feed one group a diet consisting of oatmeal, sterile hay, pasteurized milk, and water. Add orange juice to the diet of the second group. Do the two groups begin to show any signs of difference in activity, in weight, in the condition of the fur? If so, add orange juice to the diet of the first group. How long does it take for recovery?

7. What is the effect of the lack of vitamin D upon rats? Feed one group a diet of about $\frac{3}{4}$ yellow corn and about $\frac{1}{4}$ wheat gluten. Add small amounts of calcium carbonate and sodium chloride to their diet. Add cod-liver oil to the diet of the control group. Does the first group show signs of rickets? What are they? How can you bring about their recovery?

Good Books to Read

American Medical Association, *Nostrums and Quackery,* Vols. I and II. The Association.
Best, C. H. and Taylor, N. B., *The Human Body and Its Functions.* Holt.
Bogert, L. J. and Porter, M. T., *Dietetics Simplified.* Macmillan.
Carlson, A. J. and Johnson, V., *Machinery of the Body.* Univ. of Chicago.
Clendening, L., *The Human Body.* Knopf.
Cockefair, E. A. and A. M., *Health and Achievement.* Ginn.
De Kruif, P. H., *Hunger Fighters.* Harcourt.
Elwyn, A., *Yourself, Inc., The Story of the Human Body.* Brentano.
Fishbein, M., *Your Diet and Your Health.* Whittlesey.
Furnas, C. C. and S. M., *Man, Bread and Destiny.* Reynal.
Haggard, H. W., *Devils, Drugs and Doctors.* Harpers.
Hawk, P. B., *What We Eat and What Happens to It.* Harpers.
Kallet, A. and Schlink, F. J., *100 Million Guinea Pigs.* Vanguard.
Rose, M. S., *Feeding the Family.* Macmillan.
Sherman, H. C., *Food and Health.* Macmillan.
Sure, B., *The Little Things in Life.* Appleton.

UNIT IV. HOW DO LIVING THINGS PREPARE FOOD SO THAT IT CAN BE USED FOR ASSIMILATION AND OXIDATION?

Problems

1. WHAT SORT OF PREPARATION OF FOOD TAKES PLACE IN ALL ORGANISMS?
2. HOW DOES THE HUMAN BODY PREPARE ITS FOOD FOR USE IN THE CELL?
3. WHAT INTERESTING VARIATIONS IN DIGESTION ARE FOUND IN OTHER ORGANISMS?

Problem 1. What Sort of Preparation of Food Takes Place in All Organisms?

Where do assimilation and oxidation of food go on? Every organism is either one cell or is made of many cells. That idea is sometimes expressed by the statement that the cell is the "unit of structure" of living things, just as it is said that the brick is the unit of structure in a house built entirely of bricks. The cells are not just put together any which way but form regular masses which make up the body of the organism. This idea is not new to you.

But the cell is also called the "unit of function." That means that all the activities that seem to be carried on by the body are actually carried on by the individual cells. Not by the cells working apart from one another but by cells all working together. You speak of a regiment of soldiers launching an attack. The regiment is said to act but it is really the individual soldiers who are acting. It is to them you must look for the accomplishment of the work of the regiment. In the same way you would look to the cells for the performance of the activities carried on by the organism as a whole.

When the organism grows it is the protoplasm of the individual cells which assimilates and grows. When a living thing gives

Courtesy American Museum of Natural History

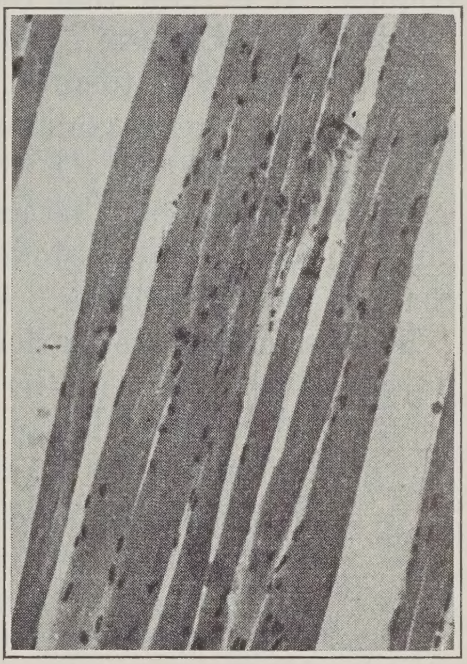
FIG. 189. Breaking up a log jam is hard work. These men need large amounts of food for assimilation and oxidation.

evidence of releasing energy, it is tiny particles of food within various cells which are being oxidized. It is the living cells that need nutrients, mineral matter, water, and vitamins for keeping alive and for doing work.

In what form must nutrients be in order to enter a cell? It is one thing to swallow food and have it disappear from view. It is quite another thing to have it enter the body. For the body, as you read above, is really a mass of cells. To enter the body, therefore, the nutrients must find their way into the individual cells and that is not so simple. Every cell is a mass of protoplasm completely surrounded by a membrane. The membrane may be extremely thin but it is as real a substance as the sheet of cellophane which encloses a box of candy. You could not push a solid piece of food through either the cellophane or the cell membrane without breaking it. You may remember that substances can pass through a cell membrane only when they are in solution. Then they enter by osmosis. *Exercise 1.*

But in most of the foods you eat the nutrients are not in solution. What is worse, they cannot dissolve even if you supply the necessary water. They are insoluble. For this reason, the first step in the preparation of food in the animal's body is a process of changing nutrients which cannot dissolve into substances which can dissolve.

What further change must take place in nutrients before they can be used by a cell? Even after they can dissolve and are able to enter each individual cell, the nutrients in food must often be changed still further in order to be usable. A man may chop down trees, pile the logs on top of one another, and build a rough log cabin. But if he wants a wholly satisfactory house he cannot use his logs without working over them; he saws them up, he planes them, he makes them into planks of regular or standard size. Food, before it can be used by anything as delicate and complex as a mass of living protoplasm, must also be refined; the nutrients must be made over into substances much less complex. But you must not think of this as a crude process like sawing and planing. In the case of the nutrients, the changes are not physical but *chemical* changes of the most complicated kind. When these changes have taken place, the proteins, carbohydrates, and fats have been made into a relatively few much simpler compounds with which the cell is able to deal. This breaking down of the nutrients into a few simple compounds which are both soluble and usable is called *digestion*.



Courtesy Gen. Bio. Supply House

FIG. 190. Much of the food eaten by the lumbermen goes to voluntary muscle cells such as these. What happens to it here?

Consider for a moment the proteins that you eat. You have learned that the protein of each kind of animal is slightly different from that of every other kind, and even more different from the proteins of plants. The protein of your cells is not exactly like any other kind of protein. Whenever you eat beef or pork or chicken or lamb or fish or any other form of protein, it cannot be changed directly into your body protein even after it is soluble. In digestion all the proteins are broken down into much simpler, smaller chemical compounds known as *amino acids.* There are only about twenty amino acids, and though you may eat proteins from a hundred different kinds of animals and plants they are always broken down by digestion into some of these simpler compounds. It is these that the cells of your body can use for the building of protoplasm. The same is true of all animals.

In the same way there is really only one kind of carbohydrate that cells can use for oxidation and that is the simple sugars which have the formula $C_6H_{12}O_6$. There are many sugars, such as milk sugar and cane sugar, that can dissolve. But in spite of this they must be broken down before they can be used. They must all be changed to simple sugars. *Exercise 2.*

By what means are nutrients digested? You have learned that protoplasm or living matter has all kinds of striking properties. Among other things, it can assimilate and grow and reproduce. But protoplasm can do something else which is just as important to it. It can make all kinds of substances which are not protoplasm and send these out of the cell; that is, cells *secrete* (see-kreet′). And if they can be used by the animal or plant the special substances sent out of the cell are called *secretions.*

The secretions are of many kinds. As they pass through the cell membrane to the outside they may come into contact with the insoluble nutrients. Then some of the secretions bring about chemical changes in the nutrients, making them soluble and usable. Such special substances secreted by the protoplasm which can digest the nutrients are known as *digestive enzymes.* *Exercise 3.*

What is peculiar about enzymes? The digestive enzymes merely act on the nutrients in such a way as to cause a chemical change in them. The enzymes themselves are not changed. Thus, given time, a small amount of an enzyme can change a large amount of nutrient since it remains just as it was originally. A chemist is familiar with substances that behave in this way. There are many of them. He calls all of them *catalysts* (kat′a-lists).

The enzymes are special catalysts secreted by living matter only. The chemist has learned to extract many of them from living cells. In fact, he can extract digestive enzymes in such large quantity that he is able to bottle them and sell them over the counter.

Digestive enzymes are not the only kinds of enzymes made by living plants and animals. There are many other kinds, with various functions, in the body of the organism. You may read of these later. Here you will read of digestive enzymes, those that act on the nutrients. There are many kinds of digestive enzymes, for each substance that is to be digested has some special enzyme to work on it. Each enzyme brings about changes in one substance and in no other. One enzyme digests protein, another fat, and so on. *Exercises 4, 5.*

Which cells are able to secrete digestive enzymes? All living cells, whether plant or animal, make digestive enzymes. It probably surprises you to read that leaf cells can digest or that the cells in your arm digest. But they do. A cell often stores food within itself in an insoluble form. In order to use it or move it the cell must first digest it.

You will remember that when you tested a leaf after a day of sunshine, it showed starch. Yet, in the morning, no starch was left in the leaf. That starch could neither have been carried away nor used up in any way at all unless it had been digested; that is, changed to soluble sugar. This means that during the night the leaf cells must have been actively making an enzyme which changed the starch to something else. This plant enzyme is called *diastase* (dy′as-tase). Every living cell, plant and animal, makes digestive enzymes. But of course cells make enzymes on a very small scale.

Where do you find cells whose main function is secreting digestive enzymes? In a complex animal there must be not only the small-scale making of enzymes mentioned above, but also secretion on a large scale. In such an animal there are billions of cells. Unlike plant cells, they cannot manufacture the nutrients, yet each cell must get its share of nutrients. The easiest way is for the animal to put all the food in one central place and gather around it cells which are particularly efficient at secreting enzymes. Then digestion can take place on a large scale. All complex animals have special organs of this sort, consisting of cells active in secreting enzymes. Such organs are an important part of the digestive system. The work of a digestive system, therefore, is to prepare food for the millions of cells. In the next problem you will see how the work is done in the animal you know best.

Exercises

1. Can starch enter an artificial cell? Prepare an artificial cell by filling a gelatin capsule with some white of egg and sugar solution. Put this in thin starch paste made by heating a small amount of starch in a large amount of water. After two hours remove the capsule and test the contents for starch. What test will you use? What do you observe? What conclusions can you draw about the entrance of starch into this cell? From what you learned in Unit II, Problem 1, which of the nutrients would you expect to be able to enter a cell?

2. How can an insoluble nutrient be made ready to enter a cell? Prepare a thin starch paste. Allow it to cool. Separate into two test tubes. To one tube add some sugar-free diastase and shake it well. Let it stand for five or ten minutes. Remove a small part of this and test it for starch. Now test some of the original starch paste for starch. Compare. Do you note any difference? If not, test the mixture of diastase and starch after more time has elapsed. Keep an accurate record of all you do. Into what soluble substance may the starch have been changed? How can you find out? Use the remnant of your mixture of starch and diastase for this test. Do not jump at conclusions. What else must you test before you can conclude that diastase makes starch ready to enter a cell?

3. Will an enzyme pass through the membrane of an artificial cell to act on the nutrient outside? Construct an artificial cell as in Exercise 1. But add to the contents of the cell a small amount of sugar-free diastase. Suspend the artificial cell in thin starch paste in a small jar. Allow it to stand at room temperature. How will you be able to determine whether the enzyme passes through the membrane out of the cell? What would be a necessary control for this experiment? What conclusions do you draw?

4. What effect does a catalyst have on a chemical change? Pour equal amounts of potassium chlorate into two Pyrex test tubes. (*Warning:* The chemical must be pure and uncontaminated by dust.) Mix a little manganese dioxide with one batch. Attach delivery tubes. Set up a trough with water. Fill two small test tubes with water to catch the oxygen. Heat the potassium chlorate until a steady stream of bubbles shows that oxygen is being produced at a steady rate. Then, using a watch, find out how long it takes to fill a test tube with oxygen. When you have finished, try the same experiment with the mixture of potassium chlorate and manganese dioxide. What difference did the manganese dioxide make? It is a catalyst in this chemical change. What is one of the properties of a catalyst?

5. Can you devise and perform an experiment to show the difference between a physical change (as in solution) and a chemical change (as in digestion)?

6. Do living plant cells digest starch? The cells of a dried kernel of corn are living but quite inactive because the seed is resting. To see activity in these living cells you must soak the kernel; it will then begin to sprout. Test the nutrients in the dried kernel. After 4 or 5 days' growth repeat the tests. What do you notice? Be sure to keep accurate notes. How can you explain what happens? Did you use a control? What was it?

Problems for Classroom Discussion

1. What reason have you for believing that the cell is the "unit of function"?

2. What kinds of chemical change can you name?

3. Why is digestion considered a chemical change?

4. Why does a higher plant not need a digestive system to work on its incoming food?

5. Some bacteria feed on meat. They have no special opening for taking in food. Where must digestion of food take place?

6. *Summary.* Look back to the question-title of Problem 1 of this unit. Write in a numbered list the new ideas you have gained about the sort of preparation of food which must take place.

Activities for the Junior Biologist

1. Does temperature affect the rate of digestion of starch by diastase? Devise and perform an experiment to answer this question. Report your results to the class.

2. Are enzymes "used up" in digestion? You read "given time, a small amount of secretion can change a large amount of nutrient since it remains just as it was originally." How could you determine the truth of that statement if you were given some prepared enzyme like diastase? Remember to use the starch in the form of a thin paste. How can you tell when the starch is completely digested?

3. Look up the subject of digestion in termites. Report to the class.

Problem 2. How Does the Human Body Prepare Its Food for Use in the Cell?

How long does it take to digest a meal? The digestion of your food is a complicated process and it takes a long time to complete. Food leaves the mouth and passes down the food pipe (*oesophagus* — ee-sof′a-gus) quickly. But then come delays. For when you eat an ordinary meal the food remains in the stomach for some time; the last of it does not leave for as much as two to four hours. It does not lie there quietly; the stomach constantly squeezes and thus mixes the food until it is a pulpy mass. Then it begins to push it bit by bit into the long narrow tube known as the small intestine. In the small intestine digestion continues; in fact, this is where most of the work is done. With enzymes acting on it all the time, the food is pushed through the coils of more than twenty feet of tubing. This takes about eight hours, after which the last of the food has probably reached the large intestine. This is a much wider tube, opening out from the small intestine in the lower right hand corner of the abdominal cavity. Digestion now is pretty well completed; no more enzymes are secreted on the food, although the changes started in the small intestine may still continue for a while. Twelve hours or more of work! To explain even a little of what occurs is a long story.

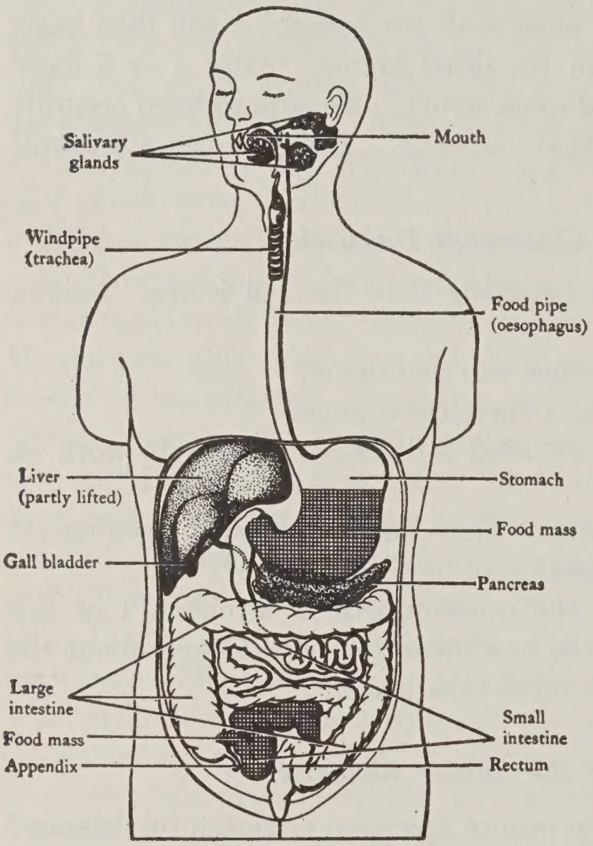

Salivary glands
Mouth
Windpipe (trachea)
Food pipe (oesophagus)
Liver (partly lifted)
Stomach
Food mass
Gall bladder
Pancreas
Large intestine
Small intestine
Food mass
Appendix
Rectum

FIG. 191. The Digestive System. The organs are not drawn in correct proportion or in exact position. Food masses are indicated at two places. If the food in the stomach was eaten at six o'clock in the evening, when was the other food eaten? What organs are shown that are not part of the alimentary canal?

How can the alimentary canal do its work? You traced the food through the long, irregular tube known as the *alimentary canal*, beginning with the mouth and ending with the large intestine. Sometimes wide, sometimes narrow, the canal winds its course through the length of the neck and the trunk for a distance of thirty feet, more or less, in a person of average size. Having such a long narrow tube instead of a short wide one is a great advantage. A meal can thus be given the twelve hours it needs for proper digestion without interfering with the next lot of food. After a few hours, the upper part of the alimentary canal is empty and ready to receive another meal. Since all the changes in the food take place while it is passing through this tube it will be interesting to learn something of its structure. *Exercise 1.*

The alimentary canal or tube is lined throughout with a delicate membrane called *mucous* membrane, which secretes the slimy, thickish substance called *mucus*. If you explore the inside of your mouth cavity with your fingers you will feel the smooth, moist membrane which helps the easy passage of food. Throughout the length of the tube, outside of the mucous membrane, are layers of muscle tissue. Some of the fibers run lengthwise, some diagonally, some in rings around the tube so that, as sets of muscles contract and relax in turn, the tube can go through all kinds of movements. These movements, of course, not only help to push the food forward into the next portion of the canal but they also help to mix the food with the enzymes.

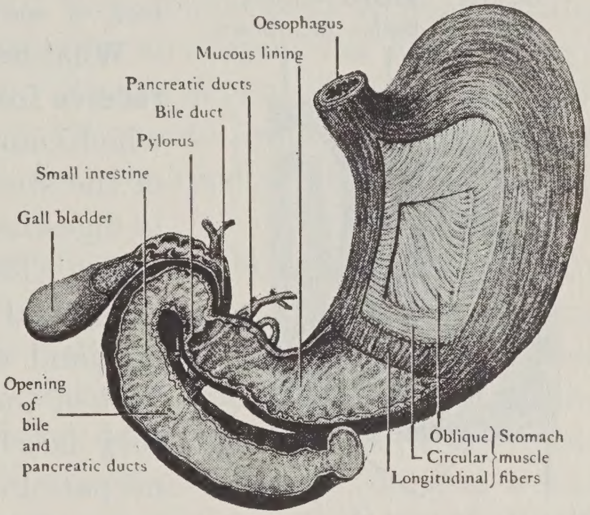


FIG. 192. This shows the lower part of the stomach and the first of the small intestine laid open to show the mucous lining. The wall of the stomach is cut to show the muscles. What would be the shape of the stomach if the circular muscles contracted?

How do the enzymes get into the canal? Where are the cells that do the real work of the alimentary canal, the cells that secrete the enzymes? In the walls of the stomach and in the walls of the upper part of the small intestine, sunk down among the muscle cells, are microscopic bags or pockets. These pockets are lined by cells which secrete enzymes dissolved in water. This mixture of water and enzymes together with some other substances secreted by the cells, is spoken of as a *digestive juice.* The juice flows out of the cells, into the bag. When the bag is full, the juice trickles through a microscopic tube, or *duct,* into a larger space and then into the stomach or small intestine, as the case may be. Such a bag of secreting cells is called a *gland.*

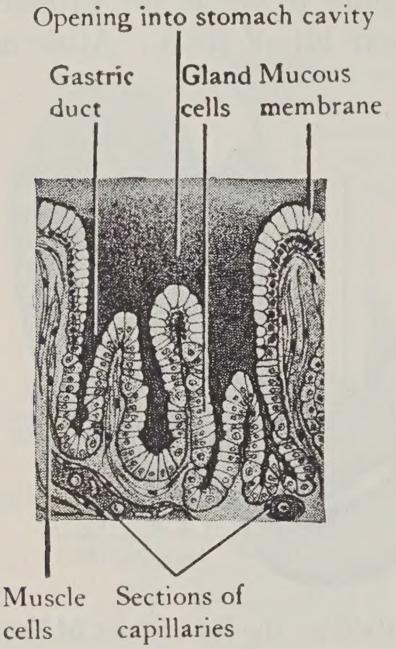


FIG. 193. A greatly magnified section through the membrane lining the stomach. Where must the gastric juice flow when the gland bags are full?

What help does the alimentary canal receive from other organs? The juices which come from the microscopic glands of the stomach and the intestine help in digestion but they do not do all the work. There are other juices, secreted by special organs consisting of masses of gland cells. These organs are not part of the alimentary canal, although they lie close to it. Since they play no part in pushing the food along they have no muscle tissue and are quite soft to the touch. Large tubes or ducts lead from these organs into the canal. The gland organs of this type are the three small pairs of *salivary* (sal′i-vary) *glands,* the *pancreas* (pan′cree-as) and the *liver.*

The salivary glands pour their juice into the mouth. Some of them open up into the sides of the cheek; others, under the tongue. The pancreas lies more or less crosswise in the abdominal cavity, behind the stomach. It pours its juice into the small intestine, close to the opening from the stomach. The liver is by far the largest gland of all, lying mostly on the right side above the stomach. It has connected with it a little storage chamber known as the *gall bladder.* The gall bladder has no gland cells, but the secretion from the liver, known as *bile* or *gall,* is held in this sac until it is needed. Then it flows out along a duct which joins the tube from the pancreas. Thus in time the bile reaches the alimentary canal. While these organs are not part of the alimentary canal through which the food is pushed, they are just as necessary to the whole process of digestion as the canal itself. *Exercises 2, 3, 4, 5, 6, 7, 8, 9.*

How is food changed in the mouth? In the mouth there is a mechanical breaking up of food. This prepares the food for digestion. The teeth and the tongue bring this about. But there is also a small amount of digestion in the mouth. *Saliva,* secreted in the salivary glands, is a digestive juice consisting almost entirely of water in which is dissolved a tiny amount of an enzyme, *ptyalin* (ty′a-lin). You will remember that an enzyme can bring about a change in one substance only. Ptyalin acts on starch, changing it to sugar. But food remains in the mouth for so short a time that little real digestion occurs before the food reaches the stomach. *Exercises 10, 11.*

How is food changed in the stomach? Have you ever noticed a dog watching the preparation of its dinner? The saliva keeps running from its mouth. And it is not only the salivary glands but also the stomach glands that are made more active by the sight and smell of food. If you could have a look at the inside of your stomach after tempting food is set before you, you would find that your stomach (gastric) glands are active also. *Gastric juice* is trickling out of all the tiny pores in the lining of the stomach.

The gastric juice like the salivary juice is largely water, but it is water containing small amounts of two very important substances. One is the enzyme *pepsin,* which changes insoluble protein to a soluble substance known as *peptone.* The other is hydrochloric (hy-dro-klor′ic) acid. This combines readily with a number of the insoluble minerals, such as calcium phosphate, which are found in our foods.

Even if the food has been well chewed it is still in fairly large masses when it reaches the stomach. During the two or more hours that it remains there it is moved back and forth and around by means of the contracting muscles in the walls of the stomach. This churning breaks up the pieces of food still further and mixes them thoroughly with the digestive juice. Meanwhile the rings of muscle at both ends of the stomach are contracted so that it is kept closed. After a while the ring at the further end relaxes and as the food is pushed about some of it is forced through into the small intestine. Then the ring contracts. After a while it relaxes again and the same process is repeated. By this method the food is delivered in small batches to the small intestine. *Exercises 12, 13, 14, 15, 16.*

What happens to food in the small intestine? When the food arrives in the small intestine some of the protein has been acted on but by no means all of it. Only very little of the starch has been converted into sugar, because the food remained in the mouth for too short a time. Minerals have been dissolved but the fats have not been touched at all; and most of the sugars, even if soluble, need further breaking down. In other words, when you take stock you find that not much has been done; it is in the small intestine that the real work goes on. There three sets of glands get busy: those in the walls of the small intestine, those in the pancreas, and those in the liver.

Consider first what the pancreatic juice does. It contains three types of enzymes; one type acts on proteins, one on starch, and one on fats. The fats are changed completely (by enzymes known as *lipases* — ly′paces) into what is practically soap and glycerine. Nothing more need be done to make them usable by the cells. The starch is converted (by an enzyme called *amylase* — am′i-lace) into soluble sugar, but not the kind of sugar the cells can use. And many of the proteins may be completely changed into amino acids. (One of the enzymes is *trypsin* — trip′sin.)

As in the stomach, the proteins are broken down into the much simpler compounds called peptones. But in most cases the action is continued so that the peptones are broken down into still simpler compounds, amino acids. Since digestion is not merely one simple chemical change but often occurs in several distinct steps or stages it is customary to speak of *intermediate products* and *end products* of digestion. End products are such substances as amino acids which need not be broken down any further. The peptones, on the other hand, would be called intermediate products. Although they are soluble, they are not usable for assimilation. The amino acids are not only soluble but can also be used at any time for making protoplasm. The enzymes in pancreatic juice convert much of the protein into its end products but leave some in the form of peptones.

Thus you can see that while pancreatic juice acts on three different nutrients, it does not change all of them into their final form. This is the work of the intestinal juice which goes into partnership with the pancreatic. The intestinal juice has an enzyme which completes the digestion of the partly changed proteins; and it has other enzymes which do the same for the sugars. Thus, while the food is in the small intestine, the nutrients are completely broken down. The bile from the liver plays no part in this directly, for it contains no enzymes. But it does make it possible for the pancreatic juice to act on fats and it helps the intestine in various other ways. *Exercise 17.*

Where do the digested foods go? Since the small intestine is only about one and a half inches wide each batch of food it receives from the stomach must be pushed along to make room for the next batch. And this must go on along the whole length of the tube. The work is done by circular muscles in the wall of the intestine which contract in regular succession along the whole length of the tube. As they contract they produce what seems to be a wave running along the intestine, a slow but rather steady wave. If you have ever watched a worm crawling you will know how the contracting intestine looks, for the same thing happens in the worm's whole body. This wave of muscular contraction is called *peristalsis* (perr-i-stall′sis).

Meanwhile, as the food is being pushed on by peristalsis it is being mixed more and more thoroughly with the juices so that digestion continues. As insoluble nutrients change to soluble they dissolve in the water of the digestive juices. These juices, you will remember, are about ninety per cent water so that they can hold much of the digested food. Naturally, as these solutions of digested nutrients wash over the cells which line the small intestine they will enter the cells by osmosis. The farther the mass of food travels along the tube and the longer the dissolved nutrients remain in contact with the mucous lining the larger the amounts which diffuse into the walls. By the time the large intestine is reached, most of the digested food has passed into the walls of the alimentary canal.

What happens to food when it diffuses into the walls of the alimentary canal? If you could slit open the intestine along its length, and if you examined the inside with a powerful magnifying glass, you would find it like the lining of your cheeks, moist and pink. But in other respects it would be different. The inside of your mouth is smooth; the lining of the small intestine is wrinkled into large folds. If your sense of touch were delicate enough and you rubbed your hand over the folds they would feel like a soft brush or like plush, for the inner wall is covered with microscopic, hairlike structures. It is into these hairlike projections that the food passes.

The hairlike projections, called *villi* (plural of *villus*), are close together. You can imagine how many thousands upon thousands of villi there must be along the whole length of the intestine. They are soft because they are made up of delicate cells.

If you have studied the figure you know how digested nutrients, minerals, and water which diffuse into the walls of the small intestine reach the blood. This absorption into the blood is necessary if all the individual cells of the body are to receive food.

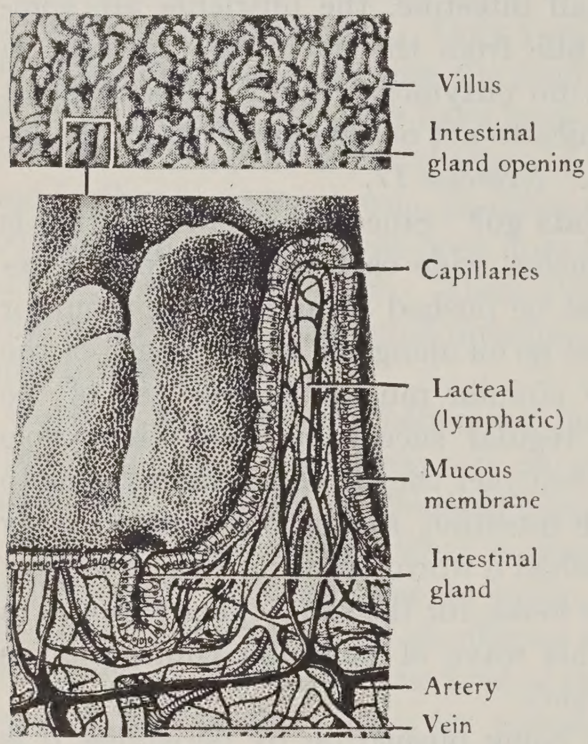


FIG. 194. The inner surface of the small intestine is covered with villi. The part that is more highly magnified has one villus drawn as if it had been cut down the middle. How many kinds of tubes does the villus contain? Can you see the openings of the intestinal glands among the villi?

Villi are found only in the small intestine, but there is a small amount of absorption in the stomach, too. Wherever there are dissolved nutrients lying close to the lining of the digestive tract for any length of time, absorption takes place. When the food is in the stomach not much of it is soluble, nor does it have an opportunity to stay in close contact with the mucous membrane, since the stomach is a large pouch instead of a narrow tube. For these reasons very little of the food is absorbed before the villi are reached. *Exercises 18, 19.*

What becomes of nondigestible food? Of course, a considerable portion of the food you eat is material other than nutrients, minerals, water, and vitamins. There are no enzymes to digest this material; it remains insoluble. The thick cellulose walls of plant cells, known as roughage, are of this type. Naturally, such substances cannot be absorbed; they are given off as wastes from the large intestine, but as they pass through the intestine they serve a useful purpose — they stimulate the walls of the small intestine to contract so that peristalsis goes on steadily and the food is moved along without too much delay.

Of what use is the liver in preparing food? You have read that the liver is a gland secreting a juice called bile or gall, and that the juice is stored in the gall bladder. Although the bile contains no enzymes its presence in the small intestine is necessary for the proper digestion and absorption of fats.

When fats are warmed by the heat of the body they turn into liquids; that is, they become oils. Sometimes you eat fat already in a liquid form as when you eat olive oil. Now when an oil is mixed with water it soon separates out from the water so that a few large drops are formed. Enzymes cannot act quickly on such large drops of oil because they can do their work only at the surface and they cannot reach the inside of the drop. The oil must be broken up into little droplets before proper digestion can go on, and that is what the bile is particularly well fitted to do. *Exercise 20.*

Bile contains a substance called a base by the chemist. A base is the opposite of an acid in many ways. Now when a base is thoroughly mixed with an oil it forms a thin film around each droplet of oil so that the droplets can no longer come together. The oil and water mixture then looks white or milky; in this condition it is said to be *emulsified* (ee-mul′si-fied). The mixture of water and tiny drops of oil is called an *emulsion.*

Both pancreatic and intestinal juices contain bases that emulsify oils in the small intestine. But bile has much stronger bases and is thus most effective in preparing fats for digestion. *Exercises 21, 22.*

What else does the liver do for the body? The liver has several other important duties to perform. Besides containing gland cells for making bile, it has ordinary cells which serve as a storehouse for large quantities of carbohydrates. You have read that all the starch and sugar of your food is converted into glucose. This is the form of sugar that the cells of the body can use. However, the blood cannot hold more than a small amount of glucose at one time. Under normal conditions, the sugar that is absorbed into the blood is rushed to the liver and stored. It is piled up there in an insoluble form similar to the starch found in a plant. This stored material is *glycogen* (gly′co-jen), which is a kind of animal starch. The process of converting glucose into glycogen is the opposite of digestion. Since glycogen is insoluble, it makes a good storage product. Of course, when this stored starch is to be put to use again, enzymes within the liver cells must change it back to glucose.

The liver has still other functions too complicated to be described here. But even if it had no other functions it would still be an organ of great importance to you.

How are the various digestive glands stirred into action? In the experiments performed by Dr. Walter B. Cannon of Harvard University he discovered that anger or excitement of any kind interferes seriously with the secretion of gastric juice in the cat. The same seems to be true of gastric glands in the human body and is certainly true of your salivary glands. Have you ever recited or spoken before an audience and noticed that your lips felt dry? Excitement stops the flow of saliva. And while excitement tends to stop the flow of saliva and gastric juice, the enjoyment of food increases their flow. Although these glands secrete slowly at all times, the state of your mind has an important effect on the rate of secretion. Sometimes it is not the enjoyment of food which starts the glands going but the mere presence of food in the alimentary canal. In either case you are not obliged to think about secretion and you are not even conscious that it takes place.

However, the digestive glands sometimes act when they have not received messages from the brain. They are stirred to action in another way. This was discovered by scientists who suspected that there were substances in the blood which stimulated the liver and the pancreas. To test their theory the following experiment was performed. Two dogs were operated upon and a large blood vessel of one dog was joined to the corresponding blood vessel of the second dog. In this way the blood of each dog flowed through the body of the other. Then one animal was fed and the other was left unfed. When the digested food arrived in the small intestine there was a flow of juices. But in the second dog, which had received no food, the juices began to flow into the small intestine just as freely. The glands of both dogs were being stimulated although one had had no enjoyment of food and had no food in its digestive tract. Evidently, therefore, it was not the brain which was stimulating the glands in the second dog. In this case it must have been the blood which came from the dog which had been fed. This experiment and similar ones were repeated, always with the same results. For this reason scientists concluded that there is something carried by the blood which stimulates the liver and the pancreas. The substance carried by the blood is called *secretin* (see-cree′tin).

Secretin gets into the blood from the mucous membrane of the small intestine. When the first digested nutrients arrive in the small intestine, they stimulate some mucous membrane cells to form secretin. The secretin is sent not into the small intestine with the digestive juices but into the blood. It circulates with the blood and promptly reaches the liver and pancreas. When it arrives there it causes the glands to secrete very actively. Secretin acts as a chemical messenger and such chemical messengers are known as *hormones*. There is believed to be a different hormone, or chemical messenger, which stimulates the stomach.

Thus each of the digestive glands is under control in one way or another and its juice appears at the time when it is needed. When something goes wrong and the gland fails to secrete, the food is not properly digested. You can see that this might easily happen.

Exercises

1. What are the parts of the alimentary canal? Study a model (manikin) or chart. Can you name the parts in order? What is the widest part of the canal? Of what advantage is it to have this part wide? Of what advantage is it to have the small intestine long and narrow? There are "valves" at three places in the canal; can you find them? (The "valves" are rings of muscle.) Of what special use is each of these valves? What part of the canal is just under the wall of the abdomen below the ribs? Draw a diagram of the canal, labeling all the parts.

2. What other organs help in the digestion of food? Find out from the model or chart the location and shape of the salivary glands, the liver, and the pancreas. If these glands make juices where must the juices go? Where does each gland join the alimentary canal?

3. What is the work of the tongue? Notice its motions when you are eating. Name two functions.

4. How does the tongue serve as an organ of taste? Put a drop of sugar water on the front of your tongue; on the back. Do you note any difference? Now put a grain or two of granulated sugar on your dry tongue. What do you discover? Blindfolded, and with nose held tightly shut, taste the following substances (someone must put them on your tongue without telling you which is which): salt, lemon juice, vinegar, sugar, something bitter, grains of ground coffee, farina, etc. Rinse your mouth after tasting each substance. Which can you recognize? Repeat, still blindfolded but breathing normally. What do you conclude? All of your observations must be carefully recorded. Compare them with those of your classmates. Why?

5. What can you discover about the number and the arrangement of your teeth? Use a mirror to discover how you bite off a piece of bread. Which teeth do the work? How are they fitted for it? You have two such teeth in each quarter of the jaw. They are called *incisors*. Which group of mammals has the incisors well developed? Right behind the incisors, you have, in each quarter, a single tooth which is somewhat more pointed. It is a *canine*, the tooth which is so large in cats and dogs and their relatives. How do the back teeth differ in shape from incisors and canines? How many back teeth are there in each quarter? What is their function? Bite into a piece of hard chewing gum. What impression does each kind of tooth make on the gum? Can you see that the two teeth directly behind the canine differ from those still farther back? How? Those farthest back are the *molars*. Between the molars and the canine lie the *bicuspids*. If you have your last molars, called wisdom teeth, and have lost no teeth, you can count 32 teeth in all. How many have you? Write a report of your observations.

6. How are the teeth fitted for their work? How does the surface of your tooth differ in appearance and in structure from the surface of a bone? Your tooth is covered with a substance much harder than bone. It is called *enamel*. Study the diagram of the tooth.

Where does the enamel end? Explain. *Dentine* is a substance much like bone. Like bone it contains cells. But enamel is pure mineral matter. What is found in the very inside of the tooth? Which are the living and which the lifeless parts of the tooth? When you have a toothache, you feel pain through the nerve. Where does the nerve lie? What has probably happened to make the tooth ache? What might cause a toothache while you were eating?

7. What can you do to make sure that your teeth are covered with a good layer of enamel? Write a paragraph on the connection between good teeth and diet. (See Unit III.) Since enamel is pure mineral matter it is not only hard but brittle. What might tend to crack it? Ask your teacher to do the following: Put into a test tube a small amount of calcium phosphate (the mineral that makes up enamel). Shake it well with a little water. Examine. Add some strong hydrochloric acid. What do you observe? Add weak acid to a very small amount of calcium phosphate and let it stand. What conclusions do you draw? When bacteria decay food they often form acids. If small particles of food are left in your mouth to decay what might happen?

8. You will find it interesting to make a list of all the rules you can think of which would (1) help to keep your teeth in good condition and (2) help the saliva do its work. Of course, unless you can give a good reason for your rule no one will be interested in it.

9. How can you show that saliva digests starch? Grind up a small piece of soda cracker and moisten it. Lay it on your tongue. What do you taste? Leave it there several minutes. What do you notice? Explain what might have happened. Did other members of the class get similar results or is this a peculiarity of your saliva?

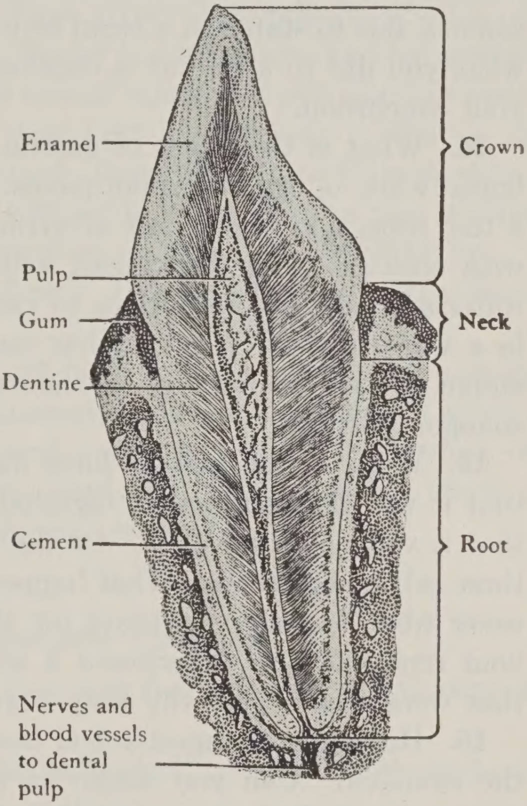


FIG. 195. Longitudinal section of an incisor.

10. What is a more scientific experiment to find out whether or not saliva (enzyme ptyalin) digests starch? Use test tubes. How will you test for sugar? (The simple sugar appears.) Be sure to have controls. What do you finally conclude about ptyalin? In what way is this experiment more convincing than the preceding one?

11. Will a chemical change in a substance go on faster if the substance is in small pieces? When you can offer suggestions for performing this experiment, ask your teacher to perform it for you. How does this experiment apply to what goes on in your mouth?

12. What is the effect of hydrochloric acid on the minerals in food? Test such minerals as table salt, calcium carbonate, calcium sulphate, sodium bicarbonate, calcium phosphate, and iron chloride. Which of these are dissolved by the hydrochloric acid of the stomach juice? Use dilute acid and very small amounts of mineral.

13. What is the effect of gastric (stomach) juice on starch? Ask your teacher to make some artificial gastric juice by adding to a test tube of water a few drops of hydrochloric acid and a little powdered pepsin. Add some of this to starch in a clean test tube. What happens? State clearly what you did to arrive at a conclusion. What was the control? State your conclusion.

14. What is the effect of gastric juice on protein? Cut some hard-boiled white of egg into small pieces. Put a quarter of a teaspoonful into a test tube, add two inches of artificial gastric juice, and plug the tube with cotton. (The experiment will be more successful if you boil the water and take all precautions to exclude bacteria.) Keep the test tube in a warm place. Why? What temperature would you suggest? Examine it after 10 minutes, 24 hours, and 48 hours. Do you note any change? Explain.

15. What in the gastric juice digests proteins? Are you convinced that it was the pepsin that digested the white of egg? Can you prove that it was not the water? Or the hydrochloric acid? Try each of the three substances alone. What happens? Now plan an experiment to discover what is really necessary for the digestion of protein. Include in your report of this experiment a statement of the control experiments that were used. Tell why they were necessary.

16. How does the mechanical breaking up of food affect digestion in the stomach? Can you devise an experiment to answer this question? (*Hint.* Use boiled white of egg.)

17. What is the effect of pancreatin on starch and protein? Pancreatin is a powder made from the pancreas of an animal. Naturally, it is not as effective as a living pancreas. Use a thin starch paste and hard-boiled white of egg. Set aside in a warm place for 24 hours. Is there any change in the nutrients? How can you tell? Is your experiment convincing?

18. Compare absorption in your body with absorption in a plant. Compare figure of root hair (use index) with figure of villus. The root hair happens to be single-celled and the villus complicated in structure, but this is of little importance. How can each structure absorb? Why can a large amount of absorption take place through each structure? Name the substances absorbed by the plant; by you. What must be true of all these substances, if they are to enter by osmosis?

19. How do villi and root hairs increase the surface used for absorption?

Fasten together several board erasers or books with an elastic. Measure their total surface area. Separate them and measure again. Compare the results. Can you explain? A cube whose side is 1 inch has a total surface area of 6 square inches. If this cube is cut up into small cubes whose sides measure .01 of an inch, there will be 1 million such cubes. What will be the total surface area of all of the small cubes? How does it compare with the area of the original cube? What is the connection between this and absorption by root hairs and villi?

20. How can oil be emulsified? Place about a teaspoonful of olive oil in a test tube half filled with water. Shake and allow to stand for several minutes. What happens? Now add a small amount of bile salts (or weak alkaline solution) and shake. You now have an *emulsion.* What is its color? Does the oil again rise to the top? Examine a drop of the emulsion under low power of the microscope. What do you see? Can you explain the emulsion? Explain how *emulsification* prepares oils for digestion.

21. Is saliva acidic or basic (alkaline)? Use litmus paper. Why must you test the saliva of many pupils?

22. Can pancreatic juice do its work in an acid medium? Add enough hydrochloric acid to a mixture of pancreatin and water to make it acidic. (Test with litmus.) Use this on starch paste and hard-boiled white of egg. (Be sure to keep all substances clean and, where possible, sterile.) What happens? How can you check your results?

Problems for Classroom Discussion

1. How can biologists discover how long food remains in any part of the alimentary canal?

2. Physicians say that some "stomachaches" are not in the stomach at all. In what organ may the pain be felt?

3. Which parts of the alimentary canal have no digestive glands in their walls?

4. Mumps is a disease of the salivary glands that produces swelling of some or all of the glands. Where would the swelling be?

5. Why does a soda cracker that is kept in the mouth for a long time taste sweeter?

6. How may bad teeth be the cause of poor digestion?

7. Why is it important to care for a child's first or milk teeth?

8. Why must the walls of the stomach be strong?

9. Explain why it is said that digestion is really the work of the pancreatic and intestinal enzymes working together.

10. Since enzymes (catalysts) are not used up in bringing about changes in food why do you need more digestive juices with each meal?

11. It is said that the solid wastes eliminated from the large intestine have never been in the body. Explain what is meant.

12. One of the commonest of all foods is an emulsion before it enters your body. Which?

13. If a person's liver or gall bladder is not functioning properly, how should his diet be modified? Why?

14. What happens when peristalsis in the stomach and oesophagus goes the wrong way?

15. Why might a monotonous diet interfere with proper digestion?

16. *For the entire class.* It is important for you to know how the human body can *best* prepare its food. If all the members of the class give this some thought and offer suggestions you can answer the question fully without help from your teacher. Go over each paragraph and each exercise you have written up to see whether it suggests to you some practical recommendation for making the digestive system work more efficiently. For example, after reading the paragraph on how the glands are stirred to action, it is easy to advise people not to eat when they are angry or excited. If the class is divided into committees, small groups of students can work together and consider each recommendation before it is offered to the class as a whole.

Summary. To test your knowledge of the process of digestion, do the following: Assume that you have taken a bite of chicken and white bread sandwich, containing butter, lettuce, salt, and some mayonnaise. Trace the complete digestion of these foods in their passage through the alimentary canal. What in this problem did you learn from personal observation and experiment?

Activities for the Junior Biologist

1. Devise an experiment to determine whether the enzyme in saliva really acts like a catalyst; that is, whether a small amount can be used over and over again without being used up in the process.

2. If saliva is swallowed with starch, can its work continue after it reaches the stomach? You must expose saliva and starch in a test tube to the surroundings they would have in the stomach. What will you do? Ask to have your experiment tried in class.

3. Soak pieces of the outer stems of celery in saliva, artificial gastric juice, and pancreatic juice. What happens? Do the same with raw carrots and boiled carrots. Explain what you observe.

4. It would be interesting to see the digestive system of some real animal. Frogs are easy to dissect. Their digestive system is in many ways like ours. You will see for yourself how it differs. Demonstrate to the class.

5. There is a tiny worm commonly found in pond water that shows peristalsis of the alimentary canal clearly when viewed under the microscope. It may be recognized by the tiny bristles and pink dots on its skin. Search for it. If you are successful, set up a slide for the class.

6. You may have wondered why the stomach, consisting of much the same material as beefsteak, does not digest itself. Look this up in Howell's *Physiology* or other college textbooks and report to the class.

7. Make a good-sized model of a gland such as would be found in the stomach or small intestine.

8. You can make plaster of paris models of your teeth by first making a wax impression or mold of them and then filling the mold with the plaster.

9. Build a large model of a villus. Papier-mâché or clay is suitable. Paint the structures so that they can be seen clearly.

10. How does alcohol affect the digestion of food? Refer to books on alcohol. What evidence do they present? What does your physician say?

Problem 3. What Interesting Variations in Digestion Are Found in Other Organisms?

How can animals improvise a stomach? Protozoa consist of a single cell and cannot have a digestive system. When the ameba eats it wraps its whole body around some smaller particle of living matter, which, of course, must be digested in order to become usable. The ameba has enclosed the food but the food is no more a part of the living animal than is the food which has disappeared from view in you and is lying in your stomach. What does the ameba do? It cannot bring the food to its stomach (it has none) so it makes a stomach of that part of itself in which the food happens to lie. The *food vacuole,* which is really a tiny drop of water containing a particle of food, becomes the stomach. The protoplasm which surrounds the food vacuole secretes enzymes which pass into the vacuole and digest the food. This improvised stomach may travel around with the streaming protoplasm, but digestion goes on nevertheless. The paramecium takes in insoluble food, too, and solves its problem in the same way. *Exercise 1.*

How do some of the simple many-celled animals digest their food? When animals are many-celled, digestion takes place in some definite region even if there is no definite alimentary canal.

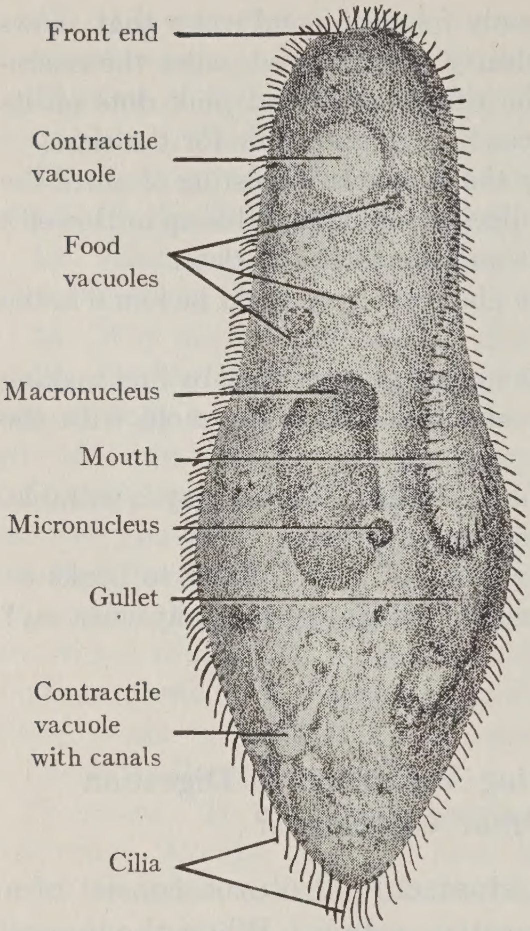

Front end
Contractile vacuole
Food vacuoles
Macronucleus
Mouth
Micronucleus
Gullet
Contractile vacuole with canals
Cilia

FIG. 196. Can you find the place where food vacuoles form in paramecium? How does the food get to this place? Where do the digested materials go?

The hydra does its digestive work in a tube closed at one end like a test tube. The tube is made of cells which secrete the enzymes.

A real alimentary canal, which resembles yours in its general form, is found in animals as simple as the earthworm. This tube runs the length of the body, opening to the exterior at both ends. Therefore, the food that lies within it is not yet a part of the body; it cannot be so until enzymes have been secreted by the walls of the canal, digestion has occurred, and absorption has taken place. You have already read how the earthworm uses its mouth for eating its way through the ground. It eats the soil in front of it and digests the particles of decaying plant and animal matter which are always present. Much of the matter of the soil cannot be digested; it is, like roughage in your food, passed to the outside through the posterior end. *Exercise 2.*

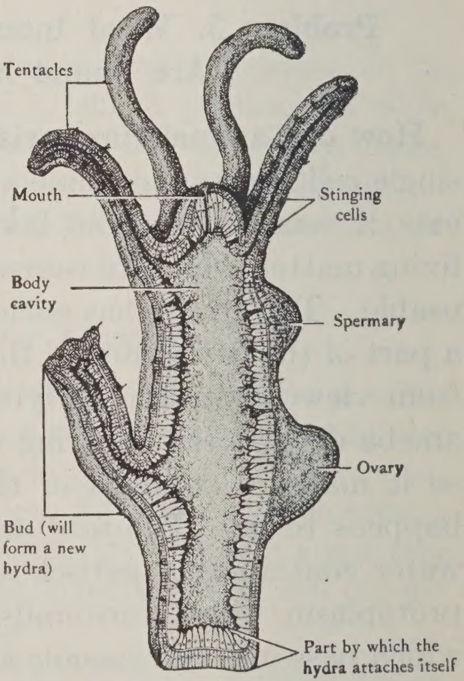

Tentacles
Mouth
Stinging cells
Body cavity
Spermary
Ovary
Bud (will form a new hydra)
Part by which the hydra attaches itself

FIG. 197. Hydra cut lengthwise. The tentacles help to capture food. Where does digestion of the food take place?

What are the problems of vegetable feeders? Vegetable foods are much more difficult to digest than most animal foods. As you know, every plant cell is surrounded by a tough wall of cellulose, and the valuable nutrients are locked up within it. Much grinding and churning are required before the contents of the cell are released. Some animals have a digestive enzyme which can dissolve this cellulose, but even when this enzyme is present, much time is required for its action. For this reason herbivores (vegetable eaters) have an extraordinarily long digestive tract. The alimentary canal of a cow is the length of half an ordinary city block, about 150 feet, or 25 times the length of the body. You can understand that it takes the food a long time to travel this distance; it must pass many cells which can work on it. In a carnivorous (meat-eating) animal like the cat, the alimentary canal is only about three times the length of the body.

In some cases the problem of a grass-eating animal is solved in another way. The food is very thoroughly chewed by means of large, flat-topped grinding teeth. On the other hand some of the herbivores graze steadily, swallowing large amounts of food without chewing it. The food goes into a pouch where it becomes moist. Later it is returned to the mouth to be chewed thoroughly at the animal's leisure. This is called "chewing the cud." The second time the food is swallowed it goes into a different pouch whence it goes on along its course.

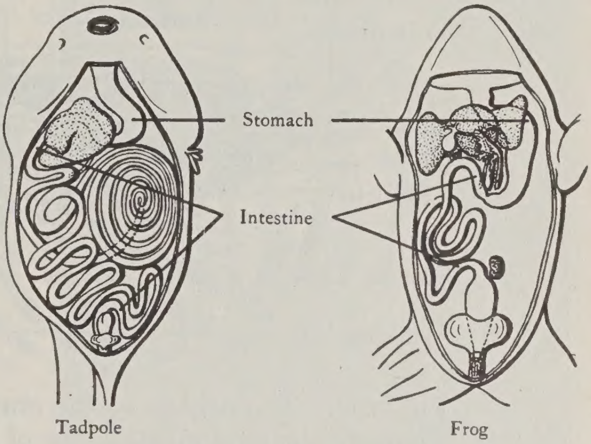


FIG. 198. The tadpole eats water plants chiefly; the frog, insects. Compare the alimentary canals.

What provisions are there for grinding food when teeth are lacking? When an animal has true teeth they are always found in the mouth, but other structures which do the work of teeth frequently develop in the stomach or in some cavity near the beginning of the alimentary canal. In the crayfish the stomach is divided into two chambers. The first one is called the gastric mill because of "millstones" which reduce the snails, insects, tadpoles, and other food to a pulp.

In the bird the lower part of the food pipe or gullet is enlarged to form the *crop* where the food is stored. When well filled this crop is easily visible. The first part of the stomach contains glands. The second part (*gizzard*) has enormously thickened muscular walls and a lining which is thick and horny. Ordinary mucous membrane would not do here for the gizzard contains stones and gravel swallowed by the bird. Here the food is well broken up.

Some animals, such as many fish and frogs and reptiles, lack grinding teeth and the food is swallowed whole. But in these cases the food is largely animal food, which is more easily digested, and the animal is probably provided with very strong digestive juices.

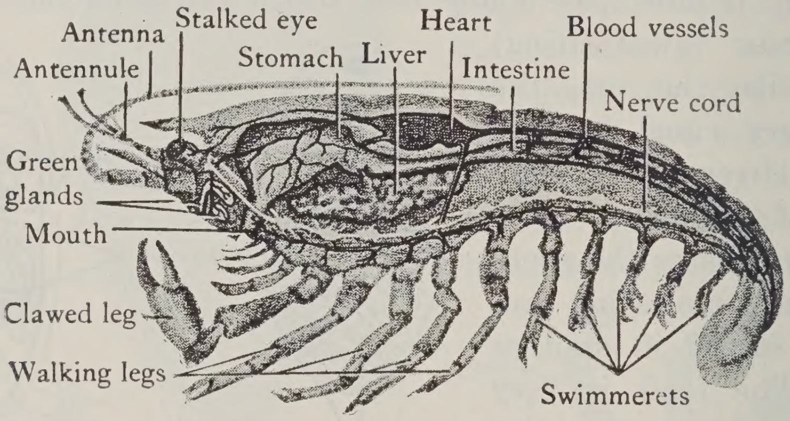


FIG. 199. The organs of the crayfish. In passing to the stomach, the food meets a row of hairlike structures which act as a sieve, keeping back the larger particles for further grinding.

In what ways are all digestive systems alike? You have just read of some of the variations in digestive systems among animals. Of course, there are many more. Yet the digestive systems of all animals are very much alike. All of them produce digestive enzymes of various kinds which are capable of changing insoluble nutrients into substances which are soluble and usable. And all of them have tubes or bags, even if they are nothing more than food vacuoles, within which the food can lie while digestion goes on. Digestion is much the same sort of process in all animals. *Exercise 3.*

How does digestion in plants compare with digestion in animals? Digestion in plants is not as different as it seems to be at first glance. To be sure, plants do not have alimentary canals or complicated digestive glands. The green plant does not need them. It is not faced with the problem of absorbing insoluble nutrients such as starch and protein into its body, for it makes these nutrients within its cells. But in order that these insoluble nutrients may be moved out of the cell, and in order that they may be used, there is digestion within each plant cell exactly like the digestion which goes on inside of every animal cell. Each cell produces its own enzymes which can make the nutrients within it soluble and usable.

There are in this part of the world a few kinds of plants which manufacture some of their own food and at the same time eat small animals. They are the insect-eating (*insectivorous*) plants. They have different devices for trapping insects and some of them have well developed gland cells for digesting their prey.

The plants which lack chlorophyll are, in one respect, more like animals than like ordinary green plants. They are unable to synthesize sugar and starch and must get their nutrients elsewhere; they find them, as do animals, outside their bodies. And since their food is in the form of complex compounds which are often insoluble they must secrete enzymes to digest it. Most of these plants are simple in structure; they have no well developed root, stem, or leaf. They settle right on the food and after enzymes have digested the material around the plant the soluble substances enter by osmosis. Digestion, in other words, takes place outside of the plant.

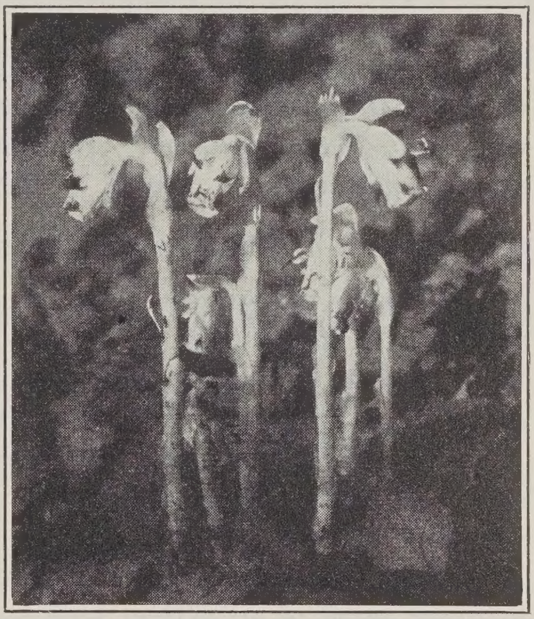


Photo by H. Schneider and J. Schwartz

FIG. 200. The Indian pipe, although one of the higher plants, contains no chlorophyll. How does it get its food?

Digestion is a process common to all living things; for all need to change insoluble nutrients to soluble substances which can be used by the living cell for assimilation and oxidation.

Exercises

1. How is digestion in a protozoan carried on? Digestion in the food vacuole of a paramecium may be followed under the microscope. Why does the food particle become smaller? What happens to the vacuole when digestion is complete? What happens to any material that is left over?

2. How is digestion carried on by hydra (or the sea anemone)? With a magnifying glass study the feeding process and report on the probable use of the central cavity for digestion. If you have sea anemones try feeding the animal blotting paper soaked in beef juice. What happens?

3. How are the alimentary canals of the various types of vertebrates fitted to do their work? Museum preparations of dissected specimens will show the alimentary canals of such animals as the fish, frog, bird, and white rat. Describe them. In what respects are they similar? How are they different?

Problems for Classroom Discussion

1. What is the source of the digestive enzymes poured into the food vacuole of a paramecium?

2. In what way is the alimentary canal of the earthworm an improvement over the stomach sac (closed tube) of the hydra?

3. Write as many rules of hygiene as you can, making practical application of what you learned about vegetable food in the paragraph on vegetable feeders.

4. Scientists sometimes reconstruct the probable shape of the alimentary canal of an extinct animal (one no longer found alive) from a study of its teeth. In general, how is this done?

5. Prepare a table showing the similarities and differences between man's alimentary canal and that of a typical herbivore or carnivore. Since man is an omnivorous (eats both plants and animals) animal, the differences are interesting.

6. *Summary.* List the most important variations in the digestive apparatus that are found in animals other than man.

7. *Unit Summary.* How can you most easily prepare an answer to the unit question? Do so. If all members of the class work together in preparing a summary it will probably be better than the product of a single pupil. Was your way of preparing the summary a good one?

Activities for the Junior Biologist

1. Study the changes in a food vacuole in an ameba. Are they like those of a paramecium or different? Report.

2. If you have cultures of Didinium (a protozoan) and Paramecium, watch the Didinium digesting the Paramecium. Report.

3. Rotifers (commonly found in pond water and cultures) have "teeth" in their stomachs. Watch the action of these under the microscope.

4. Report on the feeding habits of the crayfish. Crayfish may be kept in an aquarium.

5. Prepare a demonstration of the gizzard and crop of a chicken.

6. An interesting series of diagrams or clay models may be made showing the alimentary canals of some herbivores and carnivores.

7. Animals like the cow have complex stomachs to make "chewing the cud" possible. Look up and report on the movement of the food.

8. How could you show that a nongreen plant digests food that is outside the body? (*Hint.* Grow a mold on a slice of bread.)

9. The sundew can be found in swampy places. Feed it insects or bits of fresh meat. Report.

Good Books to Read

Best, C. H. and Taylor, N. B., *The Human Body and Its Functions.* Holt.
Carlson, A. J. and Johnson, V., *Machinery of the Body.* Univ. of Chicago.
Clendening, L., *The Human Body.* Knopf.
Cockefair, E. A. and A. M., *Health and Achievement.* Ginn.
Elwyn, A., *Yourself, Inc., the Story of the Human Body.* Brentano.
Goldschmidt, R. B., *Ascaris; the Biologist's Story of Life.* Prentice-Hall.
Hawk, P. B., *What We Eat and What Happens to It.* Harpers.
Hegner, R. W., *College Zoology.* Macmillan.
Shipley, A. E., *Life.* Macmillan.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.

UNIT V. HOW ARE THE NEEDS OF CELLS SUPPLIED IN PLANTS AND ANIMALS?

Problems

1. How Are Materials Transported to and from the Cells in Man and Other Animals?
2. How Does Oxygen Enter the Blood Stream?
3. How Are the Cells of the Body Benefited by the Giving Off of Wastes Formed in Oxidation?
4. How Are Cell Activities Regulated in Higher Animals?
5. How Does the Higher Plant Supply the Needs of Its Cells?

Problem 1. How Are Materials Transported to and from the Cells in Man and Other Animals?

What kind of transportation system do complex animals have? In the preceding unit you learned that in the alimentary canal there is large scale preparation of food for use by the cells. You know that each cell needs substances for assimilation and oxidation and that there are billions of cells, many of them far removed from the source of supplies. It is evident that there must be a system of transportation complex enough to reach every part of the body and able to carry digested nutrients to the cells.

This transportation system is made up in large part of tubes called blood vessels. It is very different from the system of pipes which carries water through a town. The water pipes, as you know, have open ends. By means of faucets in your homes you can open these pipes and allow the water to escape. But blood vessels have no openings of this kind. Unless they are accidentally torn or cut, blood vessels remain closed. Thus all the blood vessels which branch and run to every part of the body join on to other blood vessels, forming what is known as a closed system of tubes.

How does food enter the closed system of blood vessels? You know that when the nutrients have been digested in the small intestine they are absorbed by the tiny projections known as villi. Each villus contains tubes of two kinds, white ones (*lacteals*), of which you will learn more later, and red ones which contain blood. It is these blood vessels which concern you now. They are microscopic, with very thin walls. Because their walls are thin, they are well fitted for osmosis. Thus they admit soluble nutrients which have entered through the outer membrane of the villus. Such tiny blood vessels with extremely thin walls are known as *capillaries* (cap′ill-a-rees). It is by way of the capillaries of the villi that food enters the transportation system.*

How does food leave the transportation system? Not all the tubes of the transportation system have thin walls. The arteries and veins, of which you have probably heard, differ from the capillaries not only in being wider tubes but in having much thicker walls. Their walls are so thick that nothing can diffuse through them. Consequently, arteries and veins are useful only for carrying food over long distances. If food is to reach every living cell it is clear that there must be capillaries, not only in the villi, but in every part of the body. If you could examine your tissues under the microscope you would find capillaries branching among the cells just as you saw them in the diagram of the villus. *Exercise 1.*

What other substances must be transported to and from the cells? Every ordinary animal cell leads a rather busy existence, only its activities are on so small a scale that it is difficult for you to become aware of what is going on. You know that every cell needs not only food but also oxygen to carry on oxidation. Since most of the cells are far from the surface of the body there must be some provision for bringing the gas, oxygen, to each individual cell.

When oxygen and the nutrients in a cell are brought together, oxidation occurs. Energy is released; and at the same time striking changes occur in the compounds that are oxidized. New substances are formed by oxidation. Some may be harmful to protoplasm; at best, they are useless; they are called *wastes* or *excretions*. Excretions pass out of the cell by osmosis. And since the cells in a complex organism are crowded together, just as houses are in a large city, there must be provision for a steady removal of excretions from the neighborhood of each cell.

---

* You will learn of an exception later.

There are thus many substances other than the digested nutrients that are transported. An efficient transportation system is a necessity. The efficiency of the system is shown when alcohol is taken. It appears in the blood very quickly and is carried to all the cells of the body.

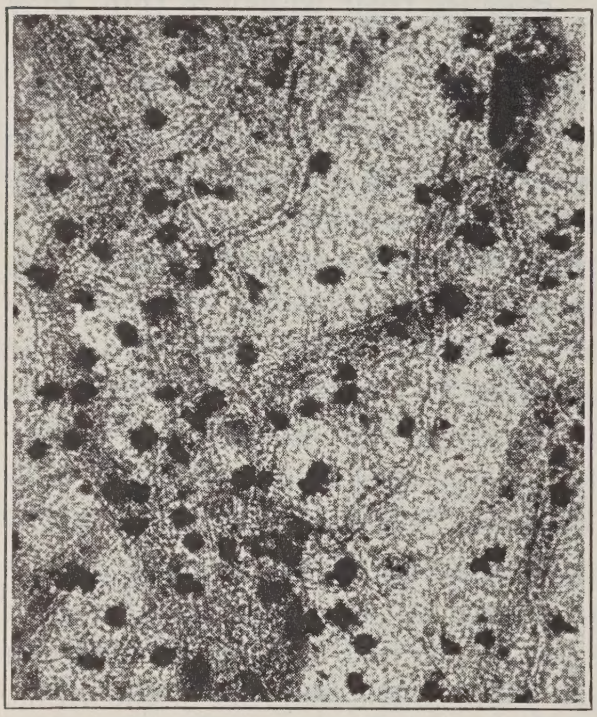


Photo by Hugh Spencer

FIG. 201. The veins and capillaries in a tiny section of the web of a frog's foot taken through the microscope at a magnification of 75 times. The dark spots are coloring matter in the skin. Can you see the faint blood vessels?

What carries the food and wastes through the blood vessels? It may astonish you to learn that it is nothing more than water that is the chief transporting agency in the blood vessels. The various nutrients and the wastes, together with some other substances, are all dissolved in the water to make a thin liquid. This solution is called *plasma.* Because of the substances dissolved in it, plasma looks straw-colored, something like a thin broth (soup). In fact, it is not unlike a broth in composition.

You can see that the composition of plasma cannot be the same at all times. If the cells in some part of the body are carrying on oxidation at a rapid rate, wastes will be poured into the plasma in large amounts. During sleep the amount of waste material present in the transportation system must be less. Some hours after a large meal, when the digestion of food is well on its way, the plasma will contain large amounts of substances produced by digestion. If the meal was rich in proteins, the plasma will be rich in the products of protein digestion, and so on for the other nutrients. You must remember that plasma is a solution of changing composition, not a fixed mixture of substances.

What makes the blood look red? The substance flowing through the transportation system looks red, as you know; you have always called it blood. The red color is caused by tiny cells that are carried by the plasma in extremely large numbers. They contain a special protein substance, rich in iron, known as *hemoglobin* (he′mo-globe′in). Hemoglobin is unlike other proteins in that it not only unites with oxygen very easily but can release it just as easily. When it unites with oxygen it forms a new compound (*oxyhemoglobin*) which is red in color. If later this red compound is in surroundings where there is little oxygen, it gives up its oxygen and changes back to maroon-colored hemoglobin.

The cells containing hemoglobin are called *red corpuscles* (kor′-puss'ls). When examined under the microscope they are disappointing, for each single cell is quite pale, even when in contact with oxygen. It is only when there are large numbers of them close together that they show the brilliant red color of fresh blood. Scientists have calculated that if all the red corpuscles of a normal person, microscopic as they are in size, were laid out next to one another they would cover an area larger than that of a baseball diamond. This does not mean much to you unless you appreciate how extremely minute each corpuscle is: 5,000,000 of them would take up only about as much room as a coarse grain of sand!

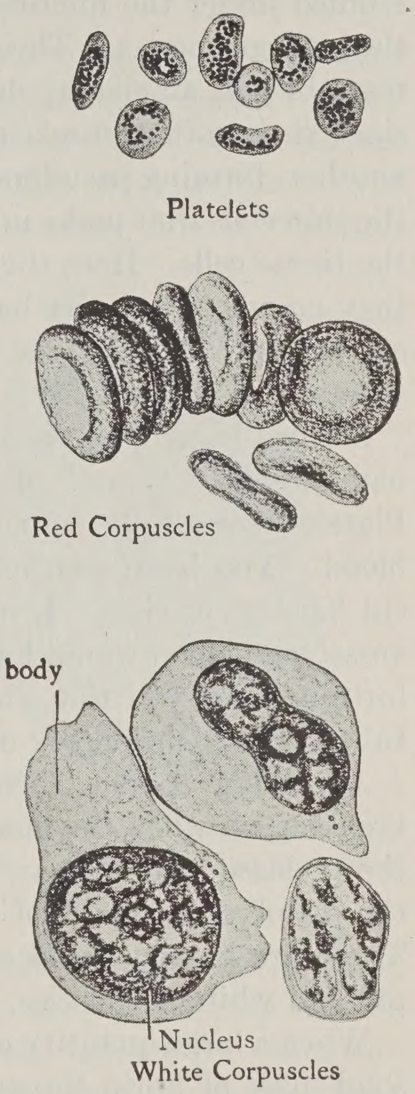


FIG. 202. How do the three kinds of blood cells differ in size? What part usually found in a cell is missing in the red corpuscles?

Some persons have more red corpuscles in a given amount of plasma than others. If the number is unusually small the person is said to have *anemia* (an-ee′me-a). Normally, red corpuscles are added to the blood stream as it flows through the red marrow of the bones. *Exercise 2.*

What other kinds of cells float in the plasma? When blood is studied under the microscope a few larger cells are found among the red corpuscles. These are known as *white corpuscles.* They resemble an ameba in shape; that is, they have no one shape, since their soft protoplasm streams now in one direction, now in another, forming pseudopods. They can push their way between the thin cells that make up the walls of capillaries and get in among the tissue cells. Here they move about much as an ameba would; they engulf and digest bacteria or any other small particles that are present. They serve as tiny scavengers (eaters of unwanted substances) in the body.

A third kind of cell is also found; it is by far the smallest. Its name, *platelet* (small plate), suggests its size and appearance. Platelets seem to be connected in some way with the *clotting* of the blood. You have seen how the blood which oozes out of a small cut hardens or clots. If it did not clot and thus plug up the blood vessel, the blood would keep right on flowing out of the cut. It is fortunate for you that the blood, when it once comes out of its tubes, has this property of hardening.

According to one theory, the platelets start the process by breaking up when the blood vessel is damaged. As they break up they release a substance. This substance indirectly causes one of the dissolved proteins of the plasma to harden and form threads. These are known as *fibrin* (fy′brin) threads. They entangle the red and white corpuscles, and this tangled mass is the clot.

When a large quantity of blood is allowed to stand in a tumbler a solid mass of fibrin threads and corpuscles forms in the way just described. This clot can then be seen floating in a faintly yellow liquid which seems to be the plasma of the original blood. But since this liquid has lost the peculiar protein which hardens into fibrin it is slightly different in composition from ordinary plasma and goes by the new name of *serum.* You may have heard that a doctor sometimes injects purified blood serum into a person.

What keeps the blood stream in constant motion? Unless there were some way of keeping these useful blood cells and the equally useful plasma in motion the cells of the body would be very badly off. Blood must travel to the farthest corners of the organism to be of use to all the cells. In an organism that walks upright blood has long distances to travel directly uphill. Yet a drop of blood can make the rounds of the body in less than half a minute. How is it done?

Blood is moved in the simplest way; it is pushed. If a liquid is put into a bag and the bag squeezed, the liquid will squirt out of the bag through any opening. If all openings but one are closed and the bag is squeezed hard the liquid will squirt out with force. The heart is so constructed that this happens every time it "beats." The walls of the heart are made of powerful muscles which by contracting do the squeezing themselves.

Instead of being one bag, the heart of a human being is really four bags. Two of these are used to push the blood into the other two; they do this gently. The second two are used to squirt the blood into big blood vessels carrying the blood away from the heart. They contract or close with great force.

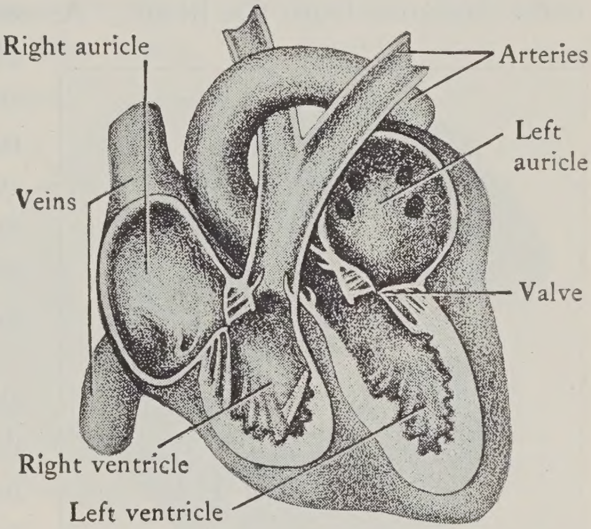
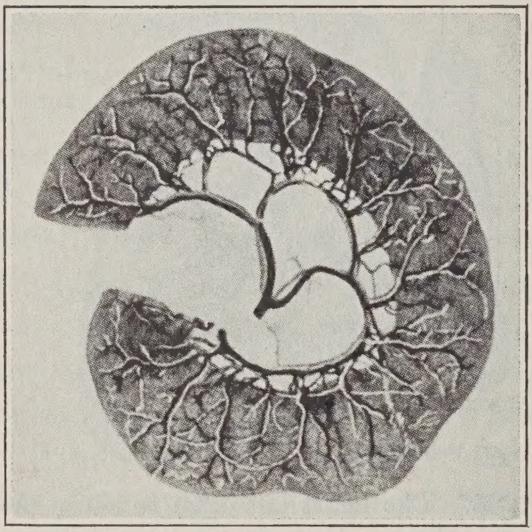


Fig. 203. The heart cut open to show the four chambers. How many large arteries open from each ventricle?

The chambers with thick walls that push blood into the blood vessels are called *ventricles* (ven′tri-k'ls); they lie side by side, so that you have a right and a left ventricle. Above the ventricles are the smaller, thin-walled chambers, the right and left *auricles* (or′i-k'ls). The outer walls of the four chambers are continuous so that from the outside the heart looks as though it were one big mass of muscle. Out of this mass there arise numerous blood vessels. Some are connected with the auricles; they are called *veins.* And from each ventricle there starts out a large blood vessel which carries the blood away from the heart. Any blood vessel that carries blood away from the heart is known as an *artery. Exercise 3.*

How do the arteries help to keep the blood moving? The ventricles contract so forcibly (you can feel this contraction through the thick chest wall) that the blood is squirted well along the artery. When a large artery is cut you can actually see the blood coming out in spurts. If the blood were pumped into a tube as wide as the chamber of the heart, or a tube made of a rigid (stiff) substance, the liquid would soon quiet down and flow smoothly. But this is not the case.

The arteries which are attached to each of the two actively pumping ventricles have walls which contain a large amount of elastic tissue. This is true of all arteries even those that are at some distance from the heart. As each rush of blood strikes these elastic walls, the artery stretches and at once comes together again, as any elastic substance tends to do. In this way the blood is squeezed within the artery and helped along its course. You can feel the walls of an artery doing this whenever you put your finger over an artery that lies near the surface. In most parts of your body the arteries are buried deep within the tissues but in your temples, in your wrists, and in some other places they are close to the skin. Here you can feel them stretching with each squirt of blood. This stretching of the artery is called the *pulse*. Each pulse beat is caused by the rush of blood sent along the artery with each contraction or pump of the heart. Thus, counting your pulse is a convenient way of counting your heartbeats. *Exercise 4.*



Courtesy N. Y. Scientific Co.

Fig. 204. A piece of the cat's intestine prepared to show branching arteries and veins.

How does the blood return to the heart? You know that blood keeps going around in circles because it flows through closed tubes. Having been pumped out of the ventricles it will soon return to the heart to be pumped out a second time. But it will have taken a long journey in the mean while and will have undergone changes in composition by the time it reappears in the ventricles. Where will it have been?

The arteries through which the blood starts out from the heart soon branch so that the blood goes in several directions. These branches subdivide again and again so that the blood is sent into all parts of the body. The finest branches of the arteries open into capillaries, which, you know, are found among all the cells. Here the spurting motion of the blood is lost. It flows more slowly and smoothly, pushed by the force of the blood behind it in the arteries. And, of course as it flows, some substances diffuse out of the plasma and others diffuse in.

Having passed through this network of microscopic capillaries which lie in every part of the body, the blood flows into wider vessels; these unite with one another, forming larger and larger vessels, the largest of which empty into the heart. These blood vessels which collect the blood from the capillaries are the veins. Their walls contain some elastic tissue, but since the blood lost its spurting motion in the capillaries it flows smoothly through the veins, forced onward by the pressure of the blood moving along in the capillaries.

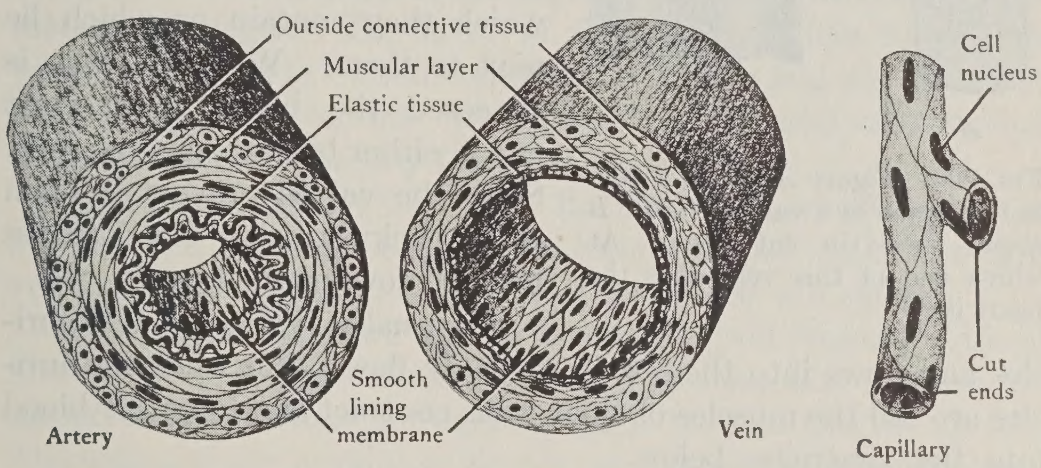


Fig. 205. What layers do you see in the wall of an artery and a vein? How do these blood vessels differ in structure? How does a capillary differ from the other two?

But the pressure of blood flowing in the capillaries is not always sufficient to push blood uphill. The blood in the veins of the legs, for example, may tend to stop and flow backward. This is prevented by *valves* which are flaps of skin like pockets on a coat. The valves lie at regular distances all along the veins.

Valves can prevent the blood from flowing backward but they cannot move it onward. You can see that even with this device, which keeps the blood from returning to the capillaries, the blood may have difficulty in getting back to the heart. But there is another force which helps to do this work. *Exercise 5.*

When you move about, particularly when you exercise, the inner parts of your body press against one another. Muscles, and even many of the internal organs, change size and shape constantly. As they do, they squeeze the veins which they contain or which lie next to them. When the vein is squeezed the blood in it must move, either backward or forward. Since the valves prevent it from going backward, the blood moves forward toward the heart.

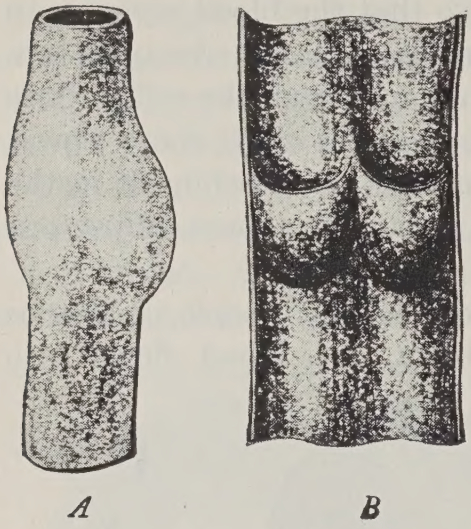


FIG. 206. Figure *A* shows a vein in the region of a valve; Figure *B* shows the vein cut open. At which end of this vein does the heart lie?

Eventually it reaches the auricles and flows into them with a steady flow. But when the auricles are full the muscles of their walls contract and force the blood into the ventricles below. If the reading of this paragraph took you ten minutes, the auricles of your heart filled and emptied themselves into the ventricles about 700 times while you were reading. Since the contraction of the auricles is immediately followed by a contraction of the ventricles your ventricles pumped blood into the arteries the same number of times in this interval.

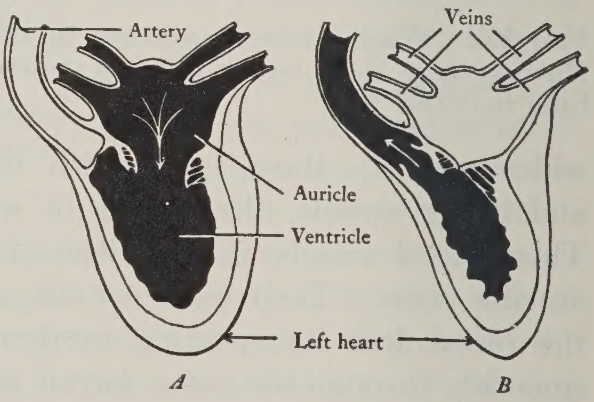


FIG. 207. Compare the valve between auricle and ventricle in figures *A* and *B*. Now look at the valve between the ventricle and the artery in *A*. What has happened in *B* as the ventricle contracted?

What prevents the blood from moving backward in the heart? In a normal heart all the blood in the auricles is pushed into the ventricles; none of it can return from the ventricles to the empty auricles because there are flaps of membrane called *valves* which act as doors. When the ventricles contract, the valves completely shut off each ventricle from the auricle above it. With the contraction of the ventricles the blood enters the arteries. And none of it has a chance to leak back into the ventricles because there are valves at the mouth of each artery. They are like the valves found inside the veins. When blood starts to flow backward toward the heart it catches in the pockets which open up and block the way back. If the edges of any of the valves do not close tightly some blood "leaks" back. *Exercise 6.*

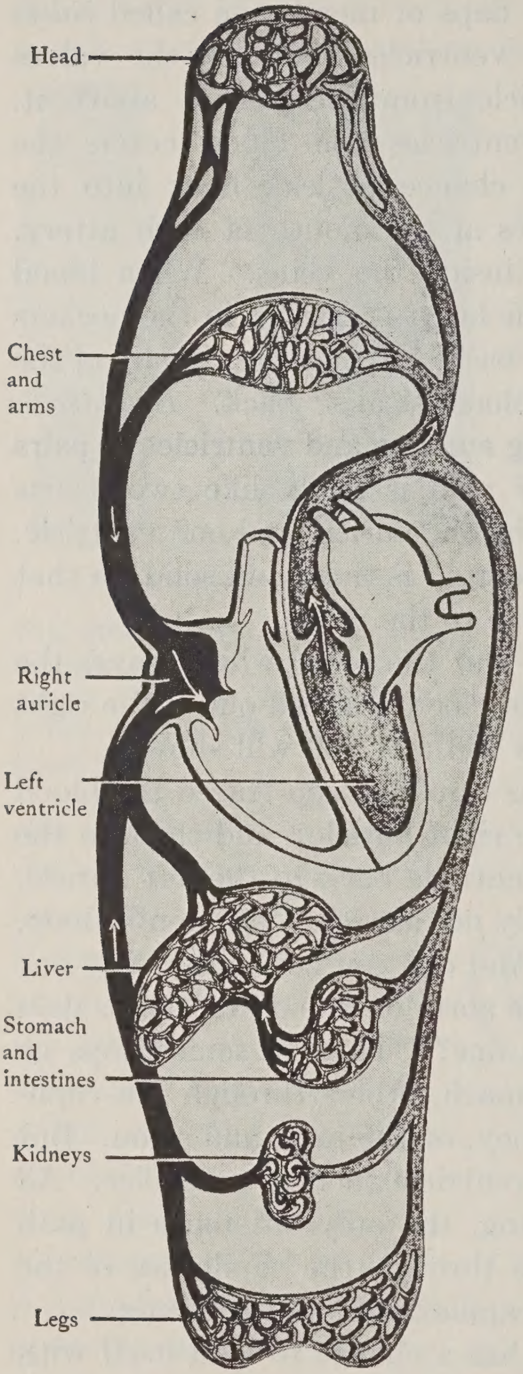
What is the advantage of having auricles and ventricles in pairs instead of single? The heart of man is really like two hearts placed side by side. Each contains one auricle and one ventricle. And the wall between the "two hearts" is thick and solid, so that no blood can pass directly from one to the other.

The two hearts beat together. But the blood which leaves the left ventricle takes one course; the blood pumped out of the right ventricle takes another, as figures 208 and 209 will show.

If you studied the two diagrams carefully you traced the blood first from the left ventricle to the right auricle; and then, in the second diagram, from the right ventricle back to the left auricle. The course of the blood is evidently not a circle but a double loop, something like the figure eight. And did you notice that any one drop of blood starting through the aorta on one of its rounds does not go to all organs but only to one? That is, some drops go through the capillaries of the stomach, others through the capillaries of the intestine, or the kidney, or the arm, and so on. But when the blood leaves the right ventricle there is no choice. All the blood must pass through a lung, the only difference in path being that half of the blood goes through the capillaries of the right lung and half through the capillaries of the left lung.

In the lung each red corpuscle has a chance to load itself with oxygen. Then the stream of blood leaves the lungs and flows through veins straight to the left auricle. While in the veins the corpuscles have no opportunity to lose any of their load of oxygen because of the thick walls of these vessels. Consequently, when the blood reaches the left ventricle it is still about as rich in oxygen as it was while in the lungs.

The blood goes on into the aorta and its various branches; part



of it into one branch, part into another, to supply all the organs of the body except the lungs. As it flows through the capillaries of any of these organs it changes its color. It is giving up its oxygen to all the cells which lie near the capillary. (It is giving up other things, too, but the loss of these does not change the color of the blood, nor are you concerned with them just now.) When the blood is collected from these organs and brought back to the heart it has little oxygen left.

If man had only one auricle and ventricle, the aorta would then have to have a branch running to the lungs as well as to the other organs, and the bright red *oxygenated* (ox′i-jen-ated — carrying oxygen) blood would go back to the single auricle. But here it would be mixed with the blood just returning from all parts of the body; it would be mixed with blood which has given up its oxygen or become *deoxygenated* (dee-ox′i-jen-ated). The result would be that all the working cells of the body would be supplied with blood which contained only a relatively small amount of oxygen.

FIG. 208. The aorta (the large artery leaving the left ventricle) is shown bringing blood to only a few organs. Which are they? Actually, there are many more branches from the aorta so that the blood is widely distributed. It goes to all the organs of the body except the lungs. To which auricle does this blood return? Note that the blood has not yet completed its circulation.

Animals like the frogs, which have two auricles but only one ventricle, get along with this arrangement. Since man has a right and a left heart and two separate blood streams, he is sure to have a richer supply of oxygen to the cells. *Exercise 7, 8.*

How do oxygen and food get from the capillary to the cell? In most parts of the body the wall of the capillary is not in direct contact with the membranes of the cells around the capillary. There are spaces between them through which all materials must pass as they go from capillary to cell or from cell to capillary.

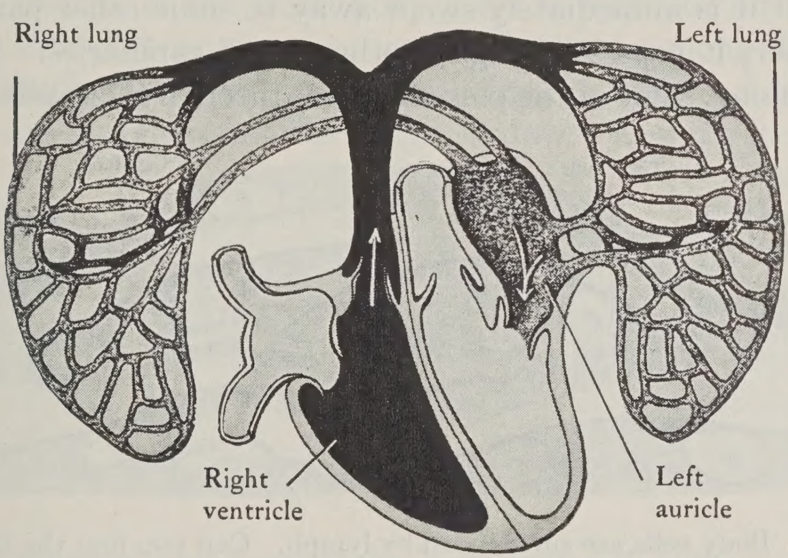


FIG. 209. Blood from the right ventricle goes to the lungs and to no other organs. To which chamber does it go from the lungs? Compare with the other diagram. The blood vessels in these diagrams are shaded to indicate the color of the blood they are carrying. What happens to the blood as it passes through the capillaries of the lungs?

If these spaces were filled with air, osmosis of materials could not take place at all. But they are filled with a watery liquid, called *lymph.* Lymph not only enables osmosis to take place through the walls of the capillaries and cells, but it also makes it possible for dissolved substances to move from place to place among the cells. You have seen lymph; it is the liquid which fills blisters. It may have looked unimportant as it oozed out of the blister but it is really as important as blood; for if your cells were not bathed in lymph they could not receive materials from the blood.

Of what is lymph composed? Lymph is mostly plasma which has escaped from the capillaries, but it contains white corpuscles, too. These are constantly pushing their way through the walls of the capillaries by means of their pseudopods. Lymph is an ever changing mixture of water, digested nutrients, various gases, and other substances. Its composition in different parts of the body varies according to the activities of the nearby cells.

How is lymph removed from the tissue spaces? After each meal, water, minerals, and digested nutrients pass into the capillaries of the villi. The blood plasma at this point becomes richer in foods but it is immediately swept away to some other part of the body where it passes through another set of capillaries. Here, as it flows along, some of the plasma passes through the capillary walls into the surrounding cells. But more plasma is being pumped into these capillaries all the time, and more oozes out. This keeps on steadily. You would expect the tissues soon to be filled and swollen with the lymph which is continually gathering. But this does not happen. There are very small closed tubes, ending in the spaces between the cells, which carry off the excess. As lymph accumulates, it passes by osmosis into these pipes or *lymphatics.*

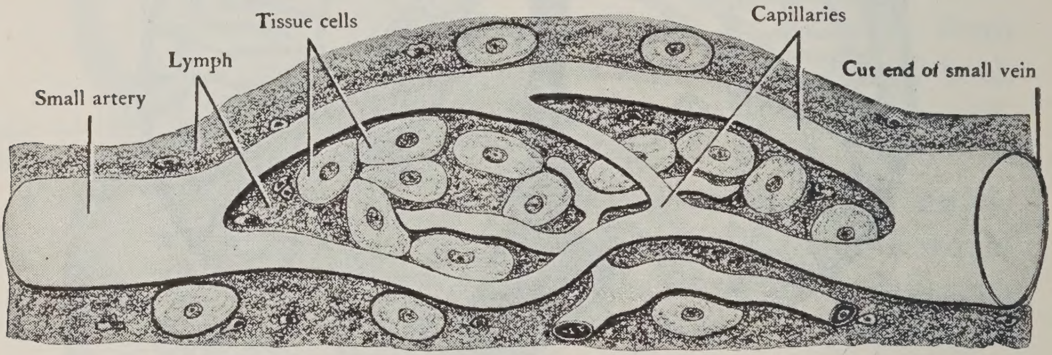


FIG. 210. Body cells are surrounded by lymph. Can you find the tubes that carry the lymph away?

Tiny lymphatics arise among the cells in all parts of the body. They meet, join together, and form ever wider and wider tubes. Finally, one good-sized lymphatic (the *thoracic duct*) pours lymph into one of the large veins on the left side of the body under the collar bone. It is here that lymph is returned to the blood stream, becoming plasma once more.

You have seen lymphatics illustrated once before although you did not recognize them as such. In the diagram of the villi there were shown tubes called lacteals. (See Fig. 194.) The lacteals are really microscopic lymphatics. They are connected with the other lymphatics. While most of the nutrients enter the capillaries in the villus, the fats pass into the lacteals. Thus fats reach the blood stream in a roundabout way.

How is lymph kept moving? Lymph that has entered the lymphatics is then pushed along by the pressure of the liquid behind. Since there is no pumping, the lymph, as is the case with the blood in the veins, sometimes tends to stand still. Here also general exercise of the whole body helps to push the liquid along. And, as in the veins, there are pocketlike valves along the length of the lymphatics to keep the lymph from flowing backward. Of course, the movement of the lymph is slow. *Exercise 9.*

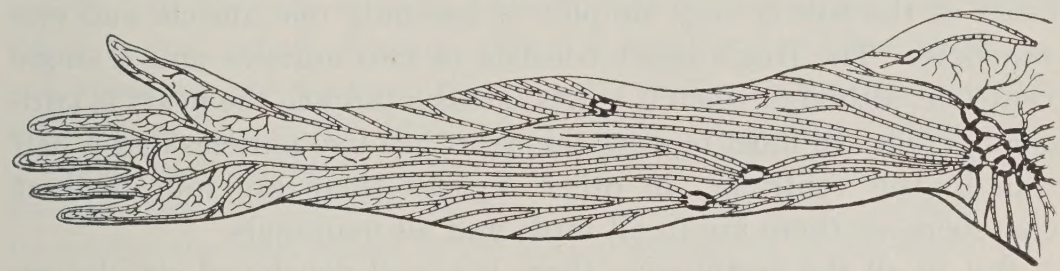


Fig. 211. Lymphatics in the arm. Lymph glands or *nodes* occur at definite places.

What kinds of blood are there in animals other than man? In all but the very simplest kinds of animals there is blood of one kind or another. Earthworms have red blood which looks just like yours. But the red color is not caused by red corpuscles. Hemoglobin is present but it is dissolved in the plasma. The insects, on the other hand, have colorless blood. Their blood vessels, therefore, carry food and wastes but little or no oxygen. The oxygen travels through the body in separate, very finely branching air tubes. The crayfish has colorless blood which turns blue on exposure to the air. In place of hemoglobin it has another substance which also combines readily with oxygen but forms a compound of a bluish color.

The vertebrates all have blood composed of colorless plasma containing red and white corpuscles. The red corpuscles vary to some extent in the different kinds of vertebrates. In some they are oval. In some they are large; in others they are smaller. But these are minor differences. The plasma also is not of exactly the same chemical make-up in the various kinds of vertebrates. *Exercise 10.*

What differences are there in the organs of circulation in the various groups of animals? In the very simple animals there are no well defined tubes for carrying food and wastes. In the earthworm there are long blood vessels running the length of the body but there is no true heart for pumping the blood. One long blood vessel and several small ones contract regularly and thus push the blood along. (See Fig. 245.) The crayfish, which is a more complex animal, has arteries, veins, and a simple heart. (See Fig. 199.)

In all vertebrates there is a heart. It is interesting to see how in each class, as you proceed from fish to mammal, the heart becomes more complicated and more efficient in its work. The heart of the fish is very simple; it has only one auricle and one ventricle. The frog's heart consists of two auricles and a single ventricle, although when it starts life as a tadpole the heart is two-chambered. In most reptiles the heart has two auricles and a half wall in the ventricle; in other reptiles there are four distinct chambers, as there are in all birds and all mammals.

But in all the vertebrates there is a well developed circulatory system which is built on the same principle as yours. In all, the blood brings food and oxygen to the cells and carries away their wastes. In the next problem you will learn how the blood gets the oxygen which it supplies to each living cell.

Exercises

1. How can you see capillaries? Wrap a wad of wet absorbent cotton around the upper part of the body of a goldfish. Tie the fish down (with a bandage) in a petri dish and cover its spread-out tail with a glass slide. Examine the edges under low power. Why are the edges best to look at? Do you see motion? Of what does the blood seem to be composed? In what directions does the blood travel? Are the vessels through which blood travels all of the same width? Since you can see the blood inside them what can you conclude about the walls of the capillaries? Does the blood ever stop for a length of time? Does it reverse its direction anywhere? Count the number of small vessels in the field. Now estimate the area of the tail in the field. What do you conclude?

2. What is the composition of blood? Wash your hands in soap and water. Sterilize the tip of one of your fingers by washing it with alcohol. Press the blood toward the tip and then prick it with a sterile needle.

Smear a drop of blood on a clean slide and cover with a cover glass. Examine under low and high powers. What is the color of the blood as you see it now? How do the corpuscles differ in appearance when they are massed in the drop? What name can you give to the substance in which the red corpuscles are floating? Examine, if you can, a stained slide of blood. What other type of cell do you now see? In what ways does it differ from the red corpuscle?

3. What is the structure of the heart? Examine a manikin or chart showing the heart in its normal position. Where does it lie? If the chart is carefully drawn, estimate the actual size of the heart. Examine a fresh beef heart, which is similar to yours. In general, what is the color of the heart? The shape? Find the auricles; these are the light-colored structures, shaped like bent ears, at the broad end of the heart. Ask your teacher to help you distinguish the right auricle from the left. How do auricles compare with ventricles in size? Feel the auricles and ventricles. What do you notice? Explain. There is usually fatty tissue along the line where left and right ventricles touch. Make incisions (cuts) about three inches long in the right and in the left ventricle. Compare the muscular walls of the ventricles with those of the auricles. Compare the right ventricle wall with the left. What differences do you note? Is the color of the heart caused by the blood it contains or by the blood flowing through its walls? How thick are the walls of the blood vessels attached to the heart? Are they all the same thickness? Insert a glass rod into each blood vessel to determine the chamber with which it connects. Blood leaves the ventricles to enter arteries.

4. What is the effect of various activities upon the pulse rate? To take your pulse place the tips of your fingers (except the thumb) on the inner part of your left wrist below the base of the thumb. Why can the pulse be felt easily here? Where else may the pulse be taken? Take your pulse while lying down completely relaxed, while sitting quietly, while standing quietly, after bending and touching the floor five times, after running swiftly for a short distance, after listening to some exciting event over the radio, and so on. Vary the activity in any way that is convenient. Record your observations. Explain the differences. Compare your sitting pulse rate with that of the other students. What is about the usual rate for your group?

5. How can you demonstrate the presence of valves in the veins? Find a place on your arm or hand where the veins show most prominently. Place your thumb on one vein and press down. Observe what happens. Release your finger. What happens now? Repeat this several times using different veins. What conclusions can you draw from your observations?

6. What keeps the blood from flowing back from ventricles to auricles? Study the beef heart into which you made two incisions. Notice the flaps of tissue held down against the sides of the ventricle by thin cords. These are the valves. When the valves close, what position is taken by the flaps? What effect would this have on the blood which tends to go back into the auricles?

7. By what device are all the organs supplied with well aerated blood? If you answer all the questions in the captions under the diagrams of circulation you will find an answer to this. Can you put together the two diagrams and show the complete circulation of the blood?

8. Do oxygen and carbon dioxide in blood change its color? Obtain fresh blood from the butcher. To keep it from clotting add a 3.8% solution of sodium oxalate. Let it stand and observe. Now bubble oxygen through it. Does it change? Now do the same with carbon dioxide. Does it lose its color?

9. The flow of blood can be stopped by a *tourniquet* (tur′ni-ket). Make a tourniquet on your forearm by knotting together two opposite corners of your handkerchief. Slip it over your arm. Slip a pencil into the knot and turn the pencil until the handkerchief makes a tight bandage. Release the bandage. Why should you not retain this tourniquet on your arm?

10. How does the blood of other vertebrates differ from man's? Examine slides of blood from such organisms as a frog, a salamander, a turtle or snake, a bird, and a mammal. Use the high power of the microscope. Draw diagrams of the corpuscles. How do they differ from man's?

Problems for Classroom Discussion

1. Why is there need for quick action when a person has been bitten by a poisonous snake?

2. State several hygienic rules (rules of healthful living) you would recommend to a person who suffers from anemia. Give reasons.

3. An old remedy for anemia was to put rusty nails into drinking water. Why do you think this would not help?

4. Why can the tissues of an animal live only a short time after the heart stops beating?

5. Why does blood flow through the capillaries in a steady flow? (*Hint.* While capillaries are microscopic they are so numerous that if they were combined they would be larger than the small arteries.)

6. When do the heart cells rest?

7. Why do physicians often order persons with leaking heart valves not to exercise actively?

8. Can you state in detail how lymph changes in composition as it flows over working muscle cells?

9. What do you think is meant by the term "blood pressure"? Why should a particularly high blood pressure be a source of danger? Would you recommend exercise or quiet for such a person?

10. What are the differences between blood and lymph?

11. Massage is given to people who are not strong enough to exercise. Would it help the circulation in the arteries, veins, or lymphatics? Explain.

12. For a cut artery would you apply the tourniquet on the side of the cut toward the heart or away from it? Why?

13. *Summary.* Look through the problem systematically and find the important facts that answer the problem question directly. Combine them into a good summary. There will be many minor points which you will not include in your summary. Make a list of these and prepare questions to ask the class to discover whether they understand these minor points.

Activities for the Junior Biologist

1. Could you make a chart showing the blood vessels as roads, a few scattered cells to which goods are delivered as buildings, and the transportation of goods to and from the cells?

2. Report on the life and work of William Harvey.

3. Report on some of the theories of the circulation of blood before Harvey's time. (See Locy, *Biology and Its Makers.*)

4. Consult the pictures in the text and the *American Red Cross Manual.* Then demonstrate to the class how to apply tourniquets for various types of cuts.

5. Look up the origin of such phrases as good-hearted, lion-hearted, gentle-hearted, and chicken-hearted. Why did some primitive tribes eat the hearts of the large, wild beasts?

6. You can demonstrate the beating of a frog's heart to the class. Etherize or chloroform a frog. (Under supervision of teacher.) Carefully dissect the frog to expose the heart. From time to time bathe the heart with Ringer's solution.

7. If bathed in Ringer's solution, the heart of a turtle or even bits of it will continue to contract even after removal from the body of the dead animal. (Use ether or chloroform.) Demonstrate this.

8. Look up and report on blood transfusions.

9. Make a model of a human heart.

10. Make a series of models of the hearts of animals in different phyla.

11. It is sometimes said that alcohol injures the arteries. On what evidence is this statement based? Present it to the class.

Problem 2. How Does Oxygen Enter the Blood Stream?

What special organs does man have for the transfer of oxygen to the blood? Large amounts of oxygen must get into the blood so that the billions of cells may be able to absorb oxygen constantly and maintain a steady oxidation. The air supplies this oxygen. In order that the body may obtain enough of it there are two special organs, the *lungs.*

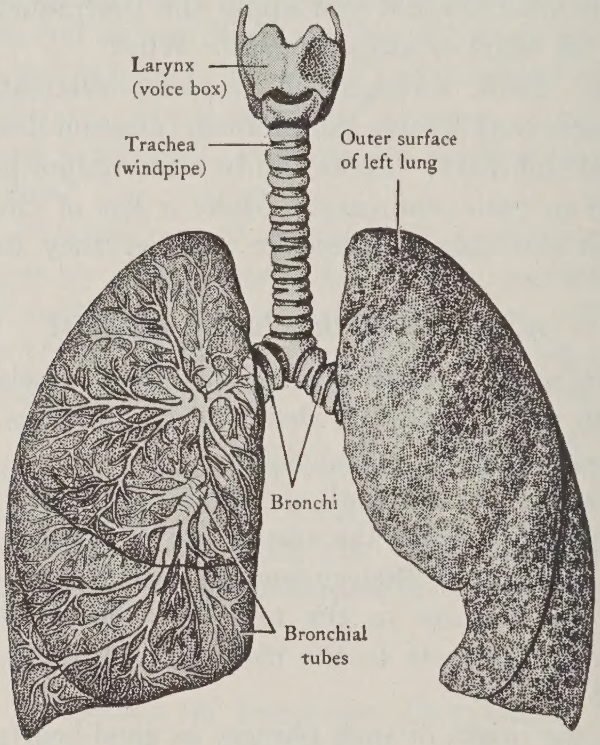


FIG. 212. One lung has been cut to show the windpipe and the larger bronchial tubes. The smallest bronchial tubes and the air sacs do not show. Why? Notice the branching.

The lungs are so placed and so constructed that they can bring an enormous amount of blood near a large quantity of air. That is their only function. They contain many capillaries which are separated from the air by thin membranes. The membranes of the lungs are not only very thin so that the oxygen can enter easily, but they are also moist. Osmosis of oxygen can take place only when the gas is dissolved in water.

As the blood flows through the capillaries of the lungs, it is brought close to the air in the bag. Then the red corpuscles in the blood can absorb oxygen as they move by. You would know from the deep pink color of the lungs that there were large amounts of blood passing through them. But by looking at them you would never suspect that these small spongy bags called lungs contain more than one hundred square yards of membrane laid over many feet of capillary tubing.

How is so vast a membrane crowded into so small a space? If you walked into the vestibule of a large apartment house, turned into the corridor, and from it entered each apartment in turn and walked through all of them you would walk a long distance. If you measured the wall space as you walked along the figures would add up astonishingly. Yet there would have been comparatively little wall space had the building been left as an empty shell. The lung is constructed on the same principle. It is not a simple bag. When air is in the windpipe it moves into two large corridors, one going to the right lung, one to the left. These corridors subdivide into smaller and smaller branches, known as *bronchial* (bron′kee-al) *tubes.* In a building, corridors open up into apartments; in the lungs, each tiny branch of the bronchial tube opens up into an *air sac.* Each air sac corresponds to an apartment; like the apartment it has little rooms opening out in all directions.

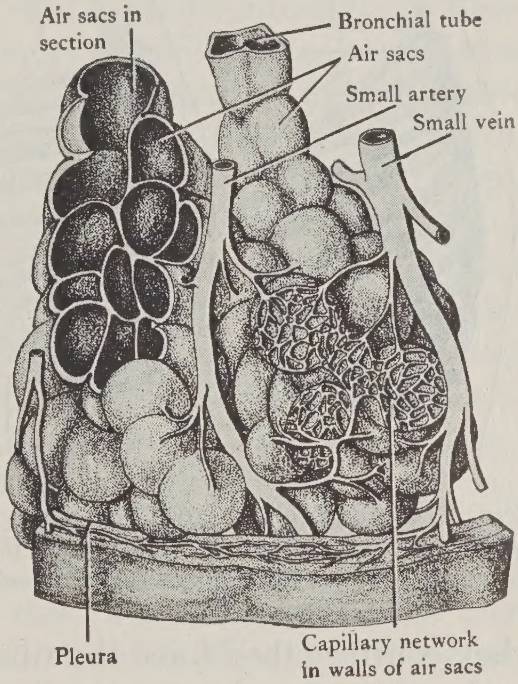


FIG. 213. A piece of lung highly magnified. There are capillaries in the walls of all the air sacs. Of what importance is this?

But here the comparison ends. Unlike the walls of the apartment, the walls of the air sacs are made of the thinnest membrane and beneath them lie the capillaries of which you read above. The walls of the air sacs differ in still another way. They are elastic so that each air sac can fold up into a small space or stretch to a great size. *Exercises 1, 2.*

Of what importance is the elasticity of the lungs? If the lungs were not elastic it would be impossible for you to breathe; that is, to take in and give out air. You have noticed that the chest moves regularly every few seconds. It grows larger and smaller, larger and smaller. And so do the lungs. When the chest cavity increases in size, the lungs do, too; when it grows smaller, the lungs grow smaller. Thus every few seconds the air sacs must change size, as the chest cavity changes size. If the air sacs were not elastic they could not keep up with the chest cavity. *Exercise 3.*

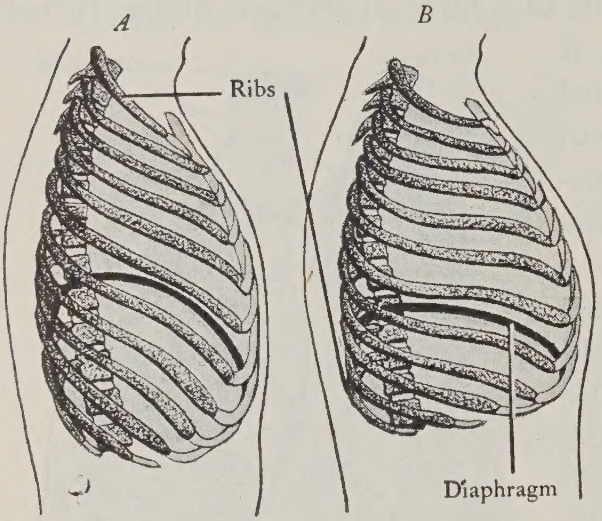


Fig. 214. Figure *A* shows the chest cavity while you are exhaling. *B* shows it while inhaling. What differences do you see?

How can you change the size of the chest cavity? You are doing it right now without thinking about it. But you can also enlarge your chest cavity purposely. Try it; take a deep breath. As you do so you can feel the muscles in your chest contracting. These muscles are attached to the ribs; when they contract they force the ribs and breast bone up and out in such a way that the chest cavity becomes larger.

This is not the only way in which the chest cavity becomes larger. A thick sheet of muscle, called the *diaphragm* (dy′a-fram), enters into the breathing movements, also. The lower wall of the chest cavity contains no bone at all; the wall is made up entirely of the diaphragm, which completely separates the chest cavity from the abdominal cavity. There are a few holes through the muscle to permit the food pipe and some of the large blood vessels to enter the abdominal cavity, but the diaphragm and the tubes are joined so closely that neither air nor liquid can slip between them.

Every time you breathe in, you are contracting this muscular diaphragm. Normally you do not feel this movement; you may never have known that it occurred. Yet when contraction occurs, it flattens the diaphragm, which in its normal position is dome-shaped. This flattening makes the chest cavity larger from top to bottom. It occurs at the same time as the raising of the ribs, so that the size of the chest cavity is increased considerably.

With the relaxation of the rib muscles the ribs once more move down and in, and when the diaphragm relaxes it moves up to take its dome-shaped position. The chest cavity thus grows smaller. *Exercise 4.*

What is the direct effect of changing the size of the chest cavity? If you dip the open end of a medicine dropper into water while squeezing the bulb and then let the bulb relax, water rushes up into the dropper. You probably know that the water is pushed up into the dropper by the force of the air pressing down on the surface of the water outside the dropper. If the medicine dropper is dipped into the water when the bulb is not squeezed, the water can rise only a little because the air inside the dropper keeps it out.

Since air cannot be seen pushing anything, many persons think that the water is "pulled up" into the dropper or they say that there is a vacuum and the water must fill it. But they are mistaken. The water is between two pressures. There is air pressure on the outside, pushing against the surface of the water in the dish, and there is air pressure on the inside, pushing against the surface of the water inside the dropper. When you squeeze the bulb, air is squeezed out of the dropper; there is less air inside than there was before. When the bulb is permitted to relax, the air pressure inside starts to get less. The greater outside pressure then pushes water into the dropper. If the bulb is squeezed hard so that most of the air is out, a great deal of water moves in and its movement is faster.

Just as water can be pushed by the pressure of air, so air itself can be pushed. When the dropper is held in air with the bulb squeezed and then the elastic bulb is allowed to get larger, air is pushed in; but you cannot see it because air is invisible. If you put the open end of the dropper into a smoke cloud you would see the smoke move in just as the water did. If you squeezed the bulb the smoke would move out.

This is exactly what happens when you breathe. While you are not breathing in or out the pressure of air in the air sacs and the pressure of air outside are equal. Air does not move in or out.

When the size of the chest cavity is increased, the wall (ribs and diaphragm) no longer presses as hard on the air sacs. The pressure of air outside the lungs is then greater than the pressure of air inside and air is pushed in. It moves through the nose and mouth passages and through the bronchial tubes into the air sacs. Just as much air flows in as will equalize the pressures. The movement of air into the lungs is called *inhaling* or breathing in.

If you then make the chest cavity smaller, the walls press on the air sacs, thus raising the pressure of air inside. Since the air pressure inside is greater than the pressure outside, air moves out of the sacs. It flows through the bronchial tubes and out of the nose and mouth passages. Just as much air leaves the lungs as will make the inside and outside pressures equal. This outward movement of air is called *exhaling* or breathing out.

During the breathing movements there is almost no friction between the chest walls and the lungs because they are separated by thin, moist, smooth membranes, called the *pleura. Exercises 5, 6, 7, 8.*

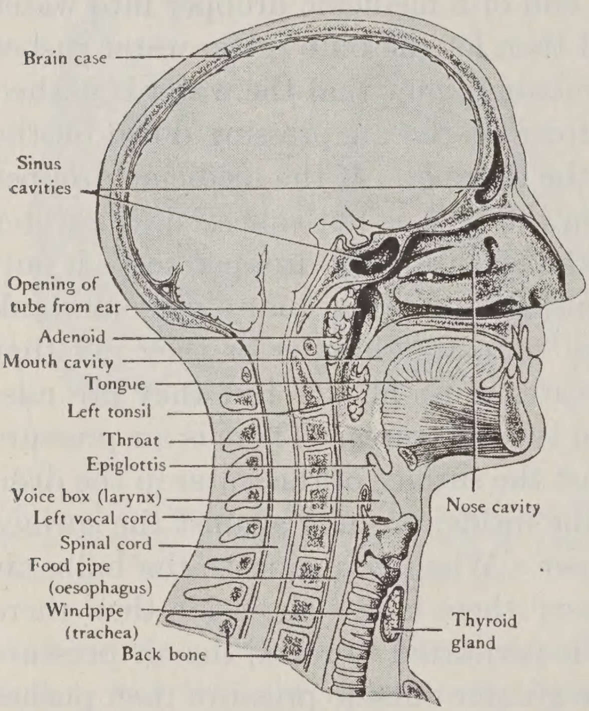

Brain case
Sinus cavities
Opening of tube from ear
Adenoid
Mouth cavity
Tongue
Left tonsil
Throat
Epiglottis
Voice box (larynx)
Left vocal cord
Spinal cord
Food pipe (oesophagus)
Windpipe (trachea)
Back bone
Nose cavity
Thyroid gland

FIG. 215. Name in order all the passages through which the air must pass in order to reach the air sacs.

To what extent can you fill and empty the air sacs? Surprisingly enough, only some of the air sacs are actively engaged in breathing. Most of them, particularly those that lie farthest away from the windpipe, neither receive nor give up air during the breathing movements. A particularly forcible contraction of the rib muscles will cause enough expansion of the chest to bring some of them into play, but even this will not send air into the most distant air sacs. In the same way, exhaling never leaves the lungs empty of air. A considerable amount remains inside. Of course, the air in these remote parts will mix somewhat with the air you take in with each breath because the gases move about by diffusion.

What happens to the air while it is in the air sacs? If the air that comes out of the lungs is analyzed so that it may be compared with the air that is breathed in, it is possible to find out just what goes on in the air sacs. This has been done. Ordinary air contains about 79% of nitrogen, less than 21% of oxygen, a fraction of 1% of carbon dioxide, and varying amounts of water vapor (which is not counted in the percentages). The air that comes out of the lungs contains the same per cent of nitrogen but only about 16% of oxygen, 4% of carbon dioxide, and much more water vapor than it had when it went in.

Biologists have concluded that when air is in the air sacs oxygen leaves the air and passes by osmosis into the blood in the capillaries. This can take place easily because there are so many capillaries just underneath the surface of the air sac membranes. Millions upon millions of red blood cells pass by during the few seconds which elapse after air has been inhaled into the air sac and before it is exhaled. The oxygen goes directly to these corpuscles, combining with their hemoglobin. There is much more oxygen than the red cells can pick up during this short interval. That is why there is so much oxygen in exhaled air.

You know that the blood must release large amounts of carbon dioxide and water at the same time that it is taking in oxygen because such large amounts of these gases appear in the air that is breathed out. You will read more about this in the next problem. While the air is in the air sacs, then, oxygen is taken out of it and carbon dioxide and water are given to it. *Exercises 9, 10, 11.*

How does oxygen enter the blood of animals living under water? All water in contact with the atmosphere has air dissolved in it. You can prove this by driving the air out of water in boiling it; but under natural conditions, of course, the air remains in the water. The animal living in the water has, therefore, an opportunity to obtain the oxygen of the air. But lungs, for some reason, are unable to extract this dissolved oxygen; it does not enter the capillaries of the lung. The blood stream of an animal whose lungs are filled with water will soon be lacking the all-important oxygen and the animal will die of suffocation.

Of course, some lung-bearing animals, such as whales and seals, live in the water. But such animals, even though they may be able to stay under water for long periods of time, always come up to the surface to breathe.

Most animals that live in the water have developed organs known as *gills,* by which they breathe. The gill is fitted for taking large amounts of the dissolved oxygen out of the water and transferring it to the blood stream. And just as lungs are useless in water, gills are useless for breathing in air. *Exercise 12.*

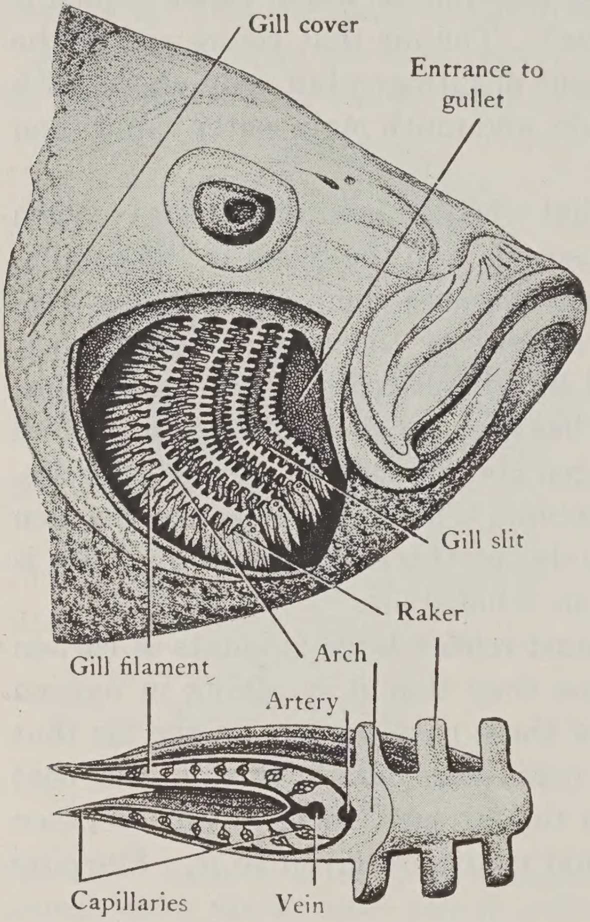


FIG. 216. In what part of the gill does the oxygen enter the capillaries? As food is washed back toward the gills, what keeps it from striking the delicate gill filaments?

How is the gill of the fish fitted to do its work? Sometimes gills develop externally (on the outside); more often they lie beneath a protective cover. This gill cover (*operculum* — oh-per′ku-lum) is arranged so that water can flow freely under it. You can see the gill cover of the fish moving in and out, now showing the bright red gills underneath, now hiding them from view. The movements of the gill cover follow the opening and closing of the mouth.

When the fish opens its mouth, water enters. When it closes its mouth, the water is pushed backward. It is not swallowed but passes over the gills lying just back of the head on either side. As the water is passing over the gills, it opens the gill cover and escapes. Thus there is a continual stream of water washing over the gills. This is necessary because the amount of oxygen dissolved in water is not great and would soon become exhausted were the water not changed continually. The diagram shows how the structure of the gill enables it to perform its work. *Exercise 13.*

How does oxygen enter the blood where lungs and gills are lacking? Some animals, like the earthworm, are covered with a thin, moist skin, directly under which lie blood vessels. Oxygen can pass by osmosis through this delicate skin in the same way that it passes through the membrane that covers the capillaries of a lung or of a gill. Frogs and salamanders, too, have a thin skin richly supplied with blood vessels. When kept moist it serves as an organ for taking in oxygen and giving off carbon dioxide.

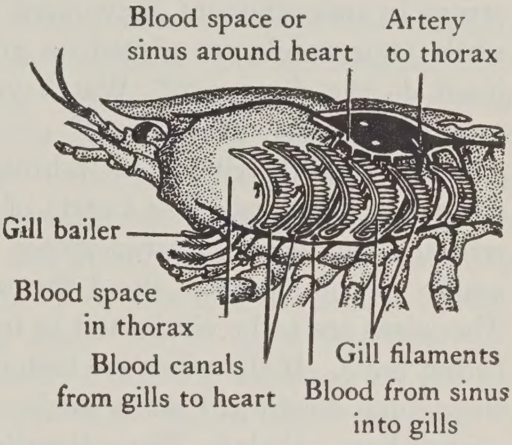

Blood space or sinus around heart
Artery to thorax
Gill bailer
Blood space in thorax
Blood canals from gills to heart
Gill filaments
Blood from sinus into gills

FIG. 217. The gills of the crayfish are protected by a hard covering. The gill bailer forces water out in front. Where does the water enter?

Of course, Amphibia (frogs and salamanders) have true lungs for supplying oxygen to their blood. These lungs are elastic but they are almost simple bags; they lack the many irregular air sacs of man's lung and consequently have much less surface for the transfer of oxygen. A thin skin fitted for breathing must be a great help to Amphibia. During hibernation, when a frog is completely buried in mud, its lungs do not function and the animal is entirely dependent on its skin. *Exercises 14, 15, 16.*

Exercises

1. What is the structure of a sheep or beef lung? Which of the structures mentioned in the text can you find in this specimen? What do you observe that has not been mentioned? Feel the outer surface and describe. This smooth membrane is part of the *pleura.* The pleura not only covers the lungs but lines the inside of the chest cavity. Of what use is a smooth membrane here? (In life it is moist.) What do you notice when you feel the windpipe? The substance in the walls is cartilage. How is the cartilage arranged? Of what advantage is the cartilage? Are these lungs collapsed or expanded? If you can, compare the weight of a piece of lung with the weight of a piece of beefsteak of the same size. Explain. Write up your observations. Compare them with others.

2. What is the internal structure of the mammalian lung? Examine a small piece of sheep or beef lung with a magnifying glass. Draw a simple diagram to show the structure. Tease the piece apart with dissecting needles. Can you see the air sacs? Are the small air tubes visible? To study the structure of the air sacs examine a prepared slide of lung tissue under the low power of the microscope. List all the structures you have seen.

3. How do you enlarge your chest cavity? Breathe out and measure your chest just below the arm pits with a tape measure. Take as deep a breath as you can and again record the size of the chest cavity. What errors in measurement may have occurred? Enlarge the chest cavity while your hands are placed on your ribs on either side. What movement do the ribs make? Watch your chest. What else occurs to make your chest cavity grow larger?

4. How do the ribs move in breathing? A model may be used to show the rib movements. Use a strip of wood, one inch by two feet, to represent the backbone. Fasten pieces of stiff wire two inches apart at right angles to this board. Bend the wires until they almost meet in front. The wires are to be connected in front by another strip, representing the breast bone. If the wires are fastened loosely, they can be moved so that they slope downward at an angle. This is the position of the ribs after air has been exhaled. Raise the ribs. What happens to the breast bone? What happens to the size of the cavity? (A simple two-dimensional model may be made by using strips of cardboard and paper fasteners.)

5. How can you demonstrate the part played by air pressure in breathing? Attach two rubber balloons to a Y-tube. Push the other end of the tube through a one-hole stopper that has been placed in the neck of a bell jar. The balloons are to hang down in the jar. Cover the large open end of the jar with rubber sheeting. The connection between sheeting and jar must be air tight. Make this model "breathe." Explain fully.

6. Under normal conditions, how long does air remain in the active air sacs before it is expelled? Count the number of times you breathe in one minute. For how much of the time is air in the sacs? Are you sure? If you can, time it with a stopwatch. What must you do to make your results dependable? When you compare your results with those of your classmates find out exactly how they interpreted the word "normal." How much time is given for the exchange of substances between the air in the sacs and the blood in the capillaries?

7. Through what passages does the air travel to reach the lungs? Close your mouth and inhale. Where does air enter? The nostrils open into the throat. Put your finger on the neck just under the chin, and speak. What do you feel? What pipe lies in the front of the neck? Does this seem to have hard or soft walls? Compare with the diagram. What name is given to this portion of the tube? What are the advantages of hard walls? Where does the food pipe lie with reference to the windpipe?

Over what must the food pass to enter the food pipe? Place your fingers on your voice box again and swallow. Describe. While you are doing this, the epiglottis which you see in the diagram moves from its upright to a horizontal position. Of what advantage is this in swallowing? What fails to happen when you "choke"? Why can you not speak and swallow at the same instant? When you get a crumb into the top of your voice box, how do you get rid of it? Explain.

8. Why is it better to breathe through the nasal cavities than through the mouth? Air contains dust which is irritating. On the dust particles are bacteria which may be injurious. Examine the entrance to your nasal cavities. How are they fitted for stopping the entrance of dust? In the upper part are microscopic cilia. Of what use might they be? The upper part of the nasal cavities and the mouth are both lined with mucous membrane. What characteristic of this membrane fits it for catching dust? Considering the width of the nasal cavities and the mouth cavity, which has a better chance of catching dust? Why? In winter when the outside air is cold, which cavity is better fitted for warming up the air on its way to the lungs? Explain. State three reasons why it is better to breathe through the nose than through the mouth.

9. What are some of the substances that you exhale? Can you devise a simple experiment to test the truth of the statement that lungs give off carbon dioxide and water?

10. How does exhaled air differ from inhaled air? Before you perform this experiment make sure you know what percentage of oxygen and carbon dioxide are normally present in the air. Blow your breath into a rubber balloon. Note how much the balloon has expanded. Then permit it to empty itself into limewater in a jar. Now pump air into the balloon until it is as large as it was before. Empty it into limewater in another jar. Examine both jars. What conclusion do you draw? Now light a candle. Invert a jar over it. Note how long the candle burns. (Use a watch.) Collect exhaled air in a jar of the same size (over water). Invert this jar over a burning candle. How long does the candle burn? What conclusion do you draw? Prepare a report.

11. What is the effect of exercise on the rate of breathing? How often do you breathe in a minute while sitting quietly? How long does air remain in the air sacs? Do setting-up exercises for one minute and then count the number of times you breathe in a minute. Explain. Compare with figures brought in by your classmates. Why is this necessary?

12. How does dissolved air get into water? Remove all dissolved air from some water by hard boiling. You can find out whether any air is left by testing for dissolved oxygen with pyrogallol. This substance will turn brown if oxygen is present. If it does not, permit the water to stand in an open vessel overnight. What color is it next day? How do you know the oxygen did not come from the water? Test your hypothesis (guess) by a control experiment. Do you see why a control is essential in experimentation? Why does a scientist reserve judgment until all the facts are in?

13. How are gills fitted to obtain oxygen? Obtain some fresh fish heads and study carefully the position and structure of the gills. Record your observations by means of words and drawings. Can you demonstrate the path taken by the water in a breathing fish by using a pencil or a splint of wood? Feel the gill cover. How is it fitted for its function? Compare with diagram. Feel the gill filaments and the gill rakers (also called gill teeth). What is the function of the gill rakers? What is the function of the filaments? Think back to the adaptations of the lung for its work of transferring oxygen to the blood; which of these adaptations do you find in the gill?

14. How does the frog breathe? The inhaling of a frog is interesting because it is so unlike man's. The frog has no diaphragm. Watch a live frog. What happens to the floor of the mouth? If the nostrils are open what is the result of lowering the floor of the mouth? As the floor goes up watch the sides of the body. What connection does there seem to be between mouth movement and body movement?

15. How does a frog's lung differ from a mammal's? Kill and dissect a frog. Note the size of the collapsed lungs. Insert a glass tube into the mouth and blow up the lungs. Compare the lungs now and the lungs before you blew air into them. Look at the lung through the light. What do you see in the walls of the lung? Cut out a piece of lung. Is the lung spongy? In proportion to size, which has a greater area exposed to air, the frog's lung or the mammal's? Why does one need more surface?

16. How can a frog's skin aid in breathing? Examine the skin of the dissected frog. Is it thick or thin? Do you find blood vessels in it? Of what use might they be? A cross section under the microscope shows large flask-shaped structures that open by a duct on the surface. They secrete mucus that helps to keep the skin moist. Of what advantage is it to have the skin moist?

Problems for Classroom Discussion

1. Why can a little sponge animal get along without lungs or gills?

2. What part of the body is affected in bronchitis? in pleurisy? in bronchial pneumonia? in lobar pneumonia?

3. Why do numerous tiny air sacs and great numbers of tiny red blood corpuscles make possible the exchange of large quantities of substances in a short time?

4. In some cases of infantile paralysis (poliomyelitis), the victim's chest muscles and diaphragm are paralyzed. If he is to be kept alive he must be put into an "iron lung." Can you figure out what the iron lung does? Check by asking a physician.

5. Explain the mechanism of your fountain pen. Why does ink enter when you are filling it?

6. If you have an inflammation of the nasal cavities (a "cold in the head"), it may turn into a cough or an earache. Study the diagram and explain why.

7. What would lead you to suspect that a child has large adenoids?

8. Why is it important that large adenoids be removed? (See Ex. 8.)

9. Why are children with large adenoids often listless and dull in school?

10. Of what advantage is it to your lungs and chest if you engage in mild regular exercise producing quicker and deeper breathing?

11. Is the gill an efficient organ for under-water breathing? How do you know? What makes it efficient?

12. Why does a fish come to the surface of the tank when the aquarium does not have enough plants?

13. Can the toad breathe as well as the frog through the skin? Explain.

14. *Summary.* The easiest method of summarizing this Problem is to state the necessary ideas in a numbered list. A somewhat more difficult procedure but one that is more accurate is to prepare an outline showing by the numbering and lettering which are the more important ideas, which the less important.

Activities for the Junior Biologist

1. Find out the best method of artificial respiration and demonstrate it to the class. (Consult *Boy Scout Handbook* or *American Red Cross Manual.*)

2. Read up about pulmotors and explain to the class on what principle they work.

3. The diaphragm is present in mammals only. What effect might the lack of a diaphragm have on the breathing of the reptiles and birds? Look this subject up and prepare a report.

4. Could you improve on the human breathing apparatus? Discuss your suggestions with your classmates.

5. If your school has no good model to illustrate breathing, make one.

Problem 3. How Are the Cells of the Body Benefited by the Giving Off of Wastes Formed in Oxidation?

What are the wastes that are formed by the living cells? Strictly speaking, the word wastes refers only to substances produced by the action of protoplasm in the cells. The solid material which passes out of the large intestine of man is not a true waste material because it never reached the body cells and was not produced by them.

The wastes formed by the cell come from oxidation. If it is carbohydrates and fats that are oxidized, their carbon and hydrogen unite with oxygen to form the simple compounds carbon dioxide and water. These are waste substances because they are not used again by the body (although, if the body does not receive enough water from other sources, some of the "waste" water may be used again).

When protein (C, O, H, N, S, P, Fe, and so on) is oxidized, other compounds besides water and carbon dioxide are formed, because so many other elements are present. The nitrogen does not unite with oxygen directly; you will remember that nitrogen is an inactive element and does not easily enter into new combinations. But, in a roundabout way, a compound consisting of carbon, oxygen, hydrogen, and nitrogen is formed. This substance is called *urea* (you-ree′a). Urea is called a waste because while it is not poisonous in small amounts, it is of no further use to the body. Another nitrogenous waste produced is *uric acid.* There are other "salts" formed that are wastes. All of these are soluble in water. *Exercise 1.*

How does the blood stream gather up and dispose of wastes? You know that the cells in an animal's body lie in a liquid known as lymph. When the wastes leave the cells they enter the lymph. The longer the lymph remains around the cells the more waste materials become dissolved in it. When the lymph drains off it finally empties itself into the blood stream. Thus the soluble waste materials soon get into the circulation and become part of the plasma.

Once in the blood, the wastes are carried about until they reach some organ which is specially fitted for taking them out of the circulation and giving them off from the body. Such organs are called *excretory* (ex′cre-tor-i) *organs* for they have the power of *excretion;* that is, each organ takes special substances from the blood, and passes them to the exterior. The organs which do this are the lungs, the kidneys, and the skin. *Exercise 2.*

How can the kidneys do their work? The kidneys are a pair of small organs that perform an extremely important function for the body. They lie in the abdominal cavity on either side of the spinal column. Each kidney is bean-shaped, about four inches long, and made up of large numbers of microscopic glands, all of which open into a large cavity. Capillaries are packed around each gland.

As blood flows by the gland cells, water leaves the plasma by osmosis; so do the dissolved urea, uric acid, and various other salts, all of which may be formed in the oxidation of proteins. This solution of waste substances, called urine, fills up the cavity of each kidney and flows down the tubes leading to the bladder. Here it is stored until it is given off from the body.

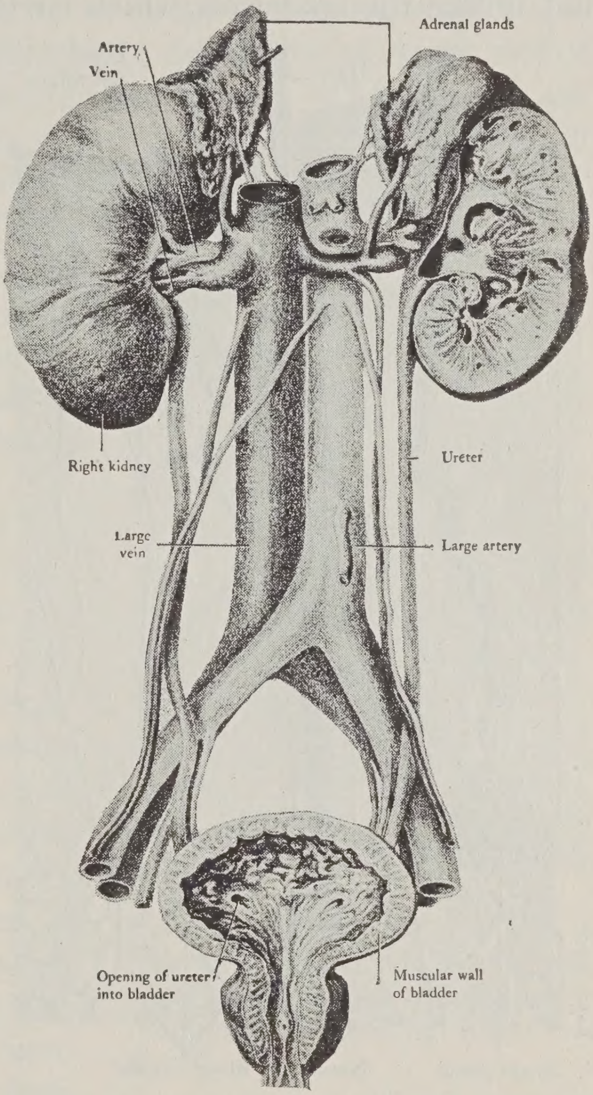


FIG. 218. The kidney on the right is cut open to show the cavity where the urine collects. Where does it go then? In what organ is it stored?

How is the skin fitted for excretion and for its other functions? Unlike the other organs, the skin is spread out over the whole surface of the body instead of being concentrated in one small mass. But it is an organ just as much as the stomach or heart or lungs, because it consists of tissues that perform some definite work for the body.

One of the tissues that make up the skin is the *epidermis*. This is not unlike the epidermis which covers leaves and other parts of plants. But in man the epidermis consists of many layers of cells of which the outermost dry up. As the protoplasm dies these outer cells become hard, thus affording protection for the various tissues underneath. Being dry, the cells tend to rub off, but new ones are being formed continually to take their place through the division of the active cells underneath. Wherever these dead cells heap up in unusual amounts a callus is formed.

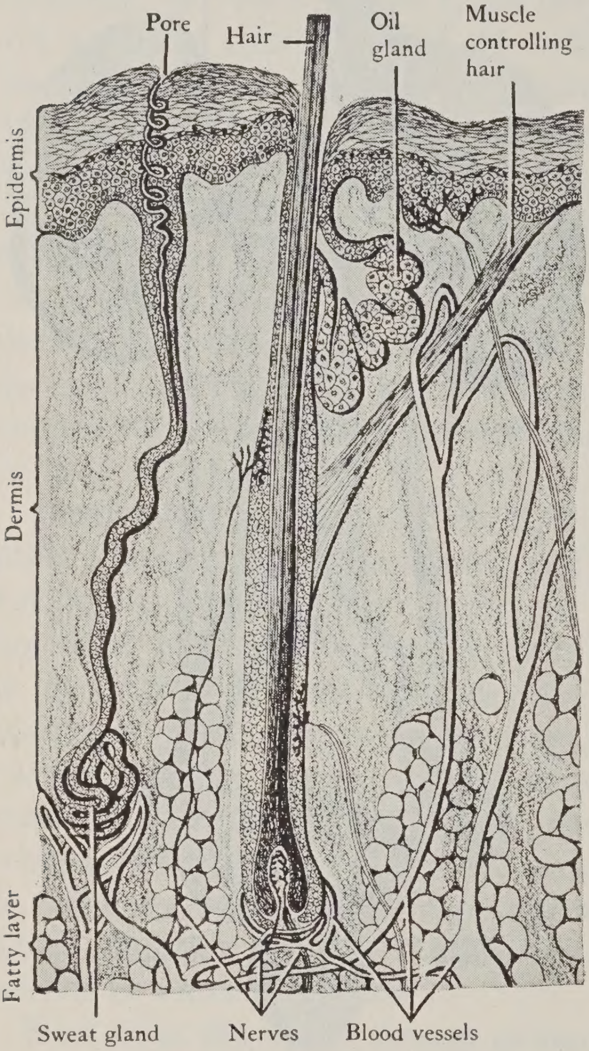


FIG. 219. Section through skin. In which layer are blood vessels lacking? Why do the outer layers of the epidermis die and dry up? What other structures are found in the dermis but not in the epidermis?

Under the epidermis lies a much thicker layer called the *dermis*. In this layer are found structures of various kinds such as the roots of the hair, tiny bands of muscle attached to the hair, special sense organs, nerves, and blood vessels. The sense organs are well protected by the epidermis, yet sufficiently near the surface to provide sensations of touch and heat and cold and pain.

But there are still other structures in the dermis that perform an important function for the body. These are the *sweat glands*. They lie in the dermis in every part of the body but in certain regions they are much more numerous than in others. *Exercises 3, 4, 5.*

How do the sweat glands work? Each sweat gland consists of a long, narrow tube which is coiled up at its lower end. It opens on the surface of the body in a pore which is visible with a magnifying glass. A network of capillaries is wrapped around each sweat gland. The gland cells receive large quantities of water and a small amount of various salts from the plasma. These wastes are then sent into the gland cavity as sweat. Since the cells do this all the time the cavity and duct of each gland are full of sweat. This overflows onto the skin from each of the many glands. The salts contained in the sweat remain on the skin while the water passes off into the air as an invisible vapor.

Since the secreting of sweat is a continuous process, one to two pints of water are lost daily in this manner by a healthy body not engaged in exercise. Yet ordinarily you are not conscious of sweat on your skin because it evaporates as quickly as it comes to the top of the duct. You become aware of it only when it pours out more rapidly than it can be evaporated from the surface. This happens during vigorous exercise or on warm days, particularly in a moist atmosphere where the evaporation of sweat is interfered with by the moisture in the air. *Exercises 6, 7, 8.*

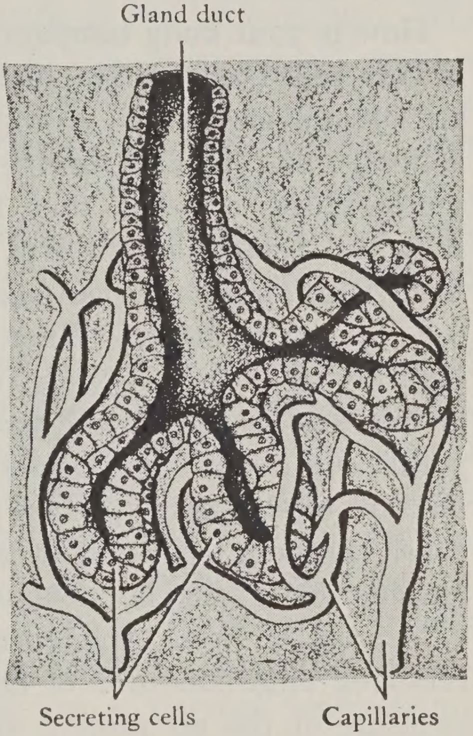


Fig. 220. Of what advantage is it to have many capillaries surrounding the secreting cells of a gland?

What happens when the work of the sweat glands is interfered with? Stop the giving off of water through the sweat glands and trouble starts. Yet the lungs and kidneys can give off excess water; in fact, most of the water lost by the body is given off by them. Then why cannot the skin be relieved of this function?

It is the *evaporation* of this water from the surface of the skin which is important. Evaporation from any surface cools the surface. And water evaporating from the skin takes heat away from the blood in the nearby capillaries and thus cools the body. When sweat can no longer evaporate your body becomes hot; your body temperature rises. This is what happens when you have fever; the sweat glands are not working properly and you cannot lose heat. Thus while the skin is an organ of excretion it is vastly more important to you as an organ for getting rid of excess heat. An important function of the skin is the regulation of body temperature. *Exercise 9.*

How is your body temperature kept uniform? The protoplasm of your cells is a sensitive, highly complex substance. If conditions be varied ever so little, protoplasm will cease to function normally. Animals and plants survive only when they are in moderate temperatures or when they have developed in such a way that they can protect themselves against extremes of heat and cold. Your body, normally, can keep the temperature surrounding your cells almost uniform. When you consider the extremes of temperature to which many of you are exposed in various climates, or at different seasons of the year, this is most amazing. Your temperature is about 98.6 degrees Fahrenheit whether you are out in a blizzard or sitting next to the radiator or stove indoors. This is because the body cells and sweat glands are working and they work automatically; that is, without your planning and thinking about it.

You know from experience that when you are exercising and releasing large amounts of heat in your body, or when the temperature of the air around you is very high, the skin looks red. That means that much blood is being sent to your skin; all the capillaries there are filled to capacity. The more blood that passes the cells of the sweat glands the more chance there is for these cells to take out water. Sweat flows freely. As a result there is much evaporation, and more heat is lost. At the same time some heat is lost directly from the skin by what is called radiation. As the blood begins to cool off it is shifted from the skin (your skin shows that, because it is less red now); that means there is less sweat. The rate of evaporation becomes less, and less heat is lost.

The body does not need a thermometer to know when to direct large amounts of blood to the skin and when to keep blood away. The nervous system automatically regulates the size of some of the small blood vessels in the skin and thus determines how much blood is to flow through the vessels.

Why do you feel discomfort in a badly ventilated room? When large numbers of people are gathered in a small space which has not enough ventilation the air soon becomes warm and heavily laden with water vapor. Evaporation slows up; the skin does not have an opportunity to lose heat and its temperature is raised.

You all know the feeling of discomfort and drowsiness that comes from being in a crowded and badly ventilated room. Formerly it was believed that the discomfort arose from inhaling air that contained too much carbon dioxide or too little oxygen. For a long time too it was thought that you breathed out minute amounts of some poisonous waste substance which was not carried off in the air and was inhaled again to poison the system. But it has been well established that the feelings of discomfort, the headache, and the general restlessness are due, at least in large part, to the inability of the skin to perform its heat-regulating function under these conditions.

To what extent is body temperature regulated in other animals? As you have learned, only birds and mammals are warm-blooded; that is, have a constant normal body temperature. The manner in which body temperature is maintained is different in these animals. Some mammals, like the horse, perspire just as man does. Others, like the dog, pant; that is, there is a rapid evaporation of water from the mouth and tongue. Regulation of body temperature is more complex in some other mammals and in the birds. The "cold-blooded" animal has a varying temperature largely determined by the temperature of the environment; that is, it cannot regulate its body temperature.

How do other animals dispose of wastes formed in oxidation? In single-celled animals like the Ameba or Paramecium wastes leave directly through the cell membrane by osmosis. But some of the wastes probably dissolve in the one or more large contractile vacuoles which are always forming. Large amounts of water are continually passing into the organism. This collects in a vacuole. When the vacuole reaches a certain size it opens and the water with its wastes is pushed out of the cell.

In all the backboned animals from the fish up, the paired kidneys are similar to man's both in position and in structure. In fact, in all the groups of many-celled animals which have a circulating fluid of some kind, there are organs which work like your kidneys.

They may be comparatively smaller and more numerous, as in the earthworm. They may be paired, but found in different parts of the body. In the crayfish the *green glands*, which seem to act as excretory organs, lie in the under part of the head!

Carbon dioxide and water are, of course, given off by lungs or gills. And the skin when it is thin and moist, as in Amphibia and earthworms, is well adapted for giving off a gas like carbon dioxide. But, in general, the skin of animals other than man is not used at all for excretion. *Exercise 10.*

Exercises

1. Can you devise an experiment to test the truth of the statement that when you burn starch or sugar, carbon dioxide and water are formed? (Remember that water vapor may be condensed and made visible by letting it rise against a cold glass.)

2. What is the structure of a lamb or a beef kidney? Cut the kidney lengthwise in half. Do you see that there is a cavity in the concave portion of the kidney? Use a strong magnifying glass to discover what opens into this cavity. Is the color of the kidney the same throughout? What do you conclude about the presence of blood? Where, do you suppose, are most of the gland cells which do the work of the kidney? Why do you think so?

3. What is an important function of the skin besides protection? As you sit still at your desk, close your eyes and move your hand until it touches something on your desk. What did it touch? How did you know? Examine the diagram for some structure which makes it possible for the skin to perform this function.

4. What other structures are found in the skin? Where does food seem to be supplied to the hair? Where is the region of growth of a hair? Of what must a hair be composed, except at its very root? Can the oil made by the oil gland be used as food by the hair? Explain. What might be the function of the oil made in the oil gland?

5. What substance is given off from the skin in large amounts? Place a clean dry vial over the thumb. Examine after some minutes. Where does this substance come from? Explain. Test some other part of the body. What result did you get? Is there any part of your body on which this does not occur?

6. Why is it necessary to clean the skin with soap and warm water? Using an evaporating dish, heat water in which are dissolved small amounts of the salts commonly given off in excretion. Continue until all the water has disappeared. What is left? Have you used a control?

What is constantly happening on a small scale on the surface of your body?

7. What is the effect of rapid evaporation from the skin? Dab some alcohol on the back of your hand and wave your hand. What do you feel? Why?

8. How does evaporation affect the temperature of an object? Take three thermometers with equal temperature readings and allow one to remain undisturbed. Place the second in a bottle of alcohol fitted with a one-holed rubber stopper. Rub a wad of absorbent cotton moistened with alcohol over the bulb of the third thermometer. Repeat this four or five times, permitting the alcohol to evaporate each time. Then read the temperatures of the three thermometers. Which has the lowest reading? Explain. Why is this a more convincing experiment than Exercise 7? Explain.

9. How much variation is there in the temperature of a normal healthy body? Take your temperature after strenuous exercise. If possible take your temperature at some time when the atmosphere is cold and you are feeling chilly. How much difference do you note? How can you explain your observations?

10. Demonstration by the teacher. Green glands in crayfish, nephridia in earthworm, kidneys in frog — in what ways are these excretory glands like those of man? In what way are they different?

Problems for Classroom Discussion

1. You should now be able to explain how secretion (as in a salivary gland) resembles and how it differs from excretion (as in a sweat gland).

2. Rapid evaporation evidently tends to cool you; slow evaporation does not cool you much. Formulate as many rules as you can think of for keeping cool on a hot day and keeping warm on a cold day. Give your reason for each.

3. What might be the danger of going out right after a hot bath on a cold day? Explain. (*Hint.* What effect does heat have on the blood supply to the skin?)

4. What is the advantage of a cool shower after a hot bath?

5. What might be the danger of sitting in a strong cool breeze after vigorous exercise has made you hot?

6. Why is it not good to permit yourself to perspire very freely just before or after a heavy meal? (*Hint.* What substance makes up the greatest part of a digestive juice?)

7. Why is so much more discomfort felt on a warm "muggy" day than on a warm dry day?

8. Is an electric fan of any real benefit or does the user merely imagine that it helps him? Explain. In a room that has no ventilation at all would a fan help? Explain.

9. Cold air is heavier than hot air and pushes the hot air to the ceiling. Which is the better way to ventilate, to raise the lower sash all the way from the bottom or raise it part way and lower the upper sash a few inches?

10. Why is the ventilation better in a room with an open fire burning than in one without a fire or with a burning stove?

11. Steam heat dries the air. What would be the effect on you of being in a steam-heated room? What can you do to obtain more normal conditions of heat and moisture in a steam-heated room?

12. *Summary.* Can you now summarize Problem 3? Were there any ideas presented that were entirely new to you? What are they? Has the problem corrected any wrong ideas that you had about the skin or the glands?

Activities for the Junior Biologist

1. How can you measure the percentage of moisture in the air of your room? Construct a wet and dry bulb thermometer. This piece of apparatus consists of two thermometers, one of which has a thoroughly wet piece of cotton cloth wrapped around its bulb. If the air can hold more moisture, water will evaporate from the wet bulb thermometer and its temperature will fall. When the wet bulb thermometer stops falling, note its temperature. What is the difference between its reading and the dry bulb reading? With the dry bulb reading and the difference in temperatures, you can find the percentage of moisture (relative humidity) in your room by consulting a relative humidity table.

2. By preparing a large thermometer containing alcohol with a little red ink in it, you can demonstrate to the class the effect of evaporation on the temperature of an object.

3. Report to the class on the Black Hole of Calcutta. Give the biological explanation of what happened.

4. How can you find out the path of the air currents in your room? Use a lighted candle. Try holding it in various parts of the room, including high up and near the floor.

5. Make a diagram of your schoolroom to show how it is ventilated. If you think that the ventilation could be improved, make a diagram of your plans. Are any of your proposed changes feasible? If so, introduce them.

6. Look up and report on methods of air conditioning.

7. Can you devise an experiment to show that such animals as fish and frogs excrete carbon dioxide?

Problem 4. How Are Cell Activities Regulated in Higher Animals?

What kinds of activities are carried on by cells? You have just learned how blood transports food and oxygen from the supply depots to the individual cells and transports wastes from the cell to the organs which excrete them. The body cells — and that includes, of course, among others, the cells which make up the excretory organs, the lungs, and the digestive organs — are never long at rest. Protoplasm is a complex mixture which is continually undergoing changes. Some of these changes result in the making of new protoplasm; these are constructive changes. Others are destructive: oxidation takes place, energy is released, and complex substances are broken down. There is thus a continual cycle of changes within every living cell, the building up of protoplasm which is known as *anabolism* (an-a′bo-lism) and its breaking down, called *catabolism* (cat-a′bo-lism). Each kind of change is dependent on the other. The whole cycle of change goes by the name of *metabolism* (met-a′bo-lism).

How are the metabolic activities of cells regulated in a higher animal? If all of the billions of cells in a higher animal are going through metabolic (met-ȧ-bo′lic) changes and these cells are to work together there must be some regulation of their activities. The nervous system does much of this. But some of it is also done by chemical substances secreted into the blood by special organs.

One such chemical regulator was described earlier. Its name is secretin; it regulates the activity of the secreting cells in the pancreas and liver. You may recall that the name hormone is given to such a substance. Another name is *internal secretion,* given because the secretion goes directly into the blood instead of passing out by way of a duct into the intestine or some other organ. There are many internal secretions; each one has an important effect on the activities of some or all of the body cells.

How is energy production in the cells of higher animals regulated? One of the most important of the hormones (internal secretions) is a substance named *thyroxin,* which is found in the blood at all times. Unlike secretin, it affects not one organ or a few but all the cells of the body. Normally, thyroxin is present in the blood in extremely small amounts, yet it has a powerful effect on the cells. Although the way in which it does its work is not understood, it is known that thyroxin speeds up the rate of oxidation in all parts of the body. In other words, thyroxin has an important effect on the metabolism of the cells of the human body.

When thyroxin increases oxidation in the cells of the brain there is great mental activity; through its action in other parts of the body muscular activity is increased; and in the early years of life it hastens metabolism in the cell so that growth processes go on at a faster rate. Thus, thyroxin promotes growth and development in the child.

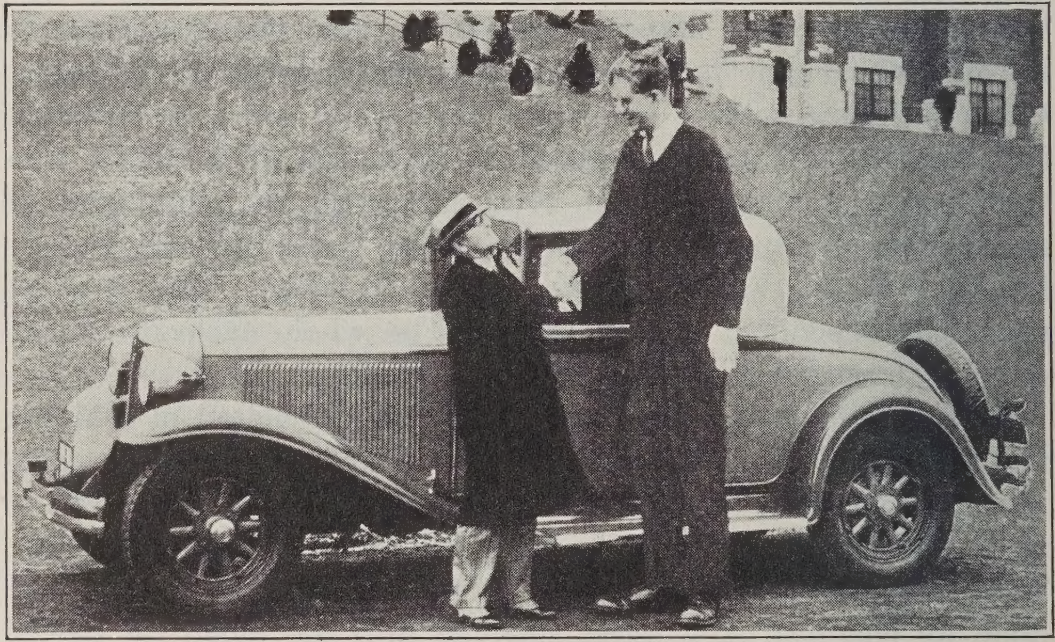


Photo by Acme

Fig. 221. Robert Wadlow at the age of 15. He is now 8 feet 7 inches tall and weighs 450 pounds. How can you explain his size?

Thyroxin promotes growth and development and whips up oxidation in all vertebrates. This can be shown by experiments with the frog. If small amounts of thyroxin are added to the water in which tadpoles are kept they change into frogs much more rapidly. In fact, so rapidly does this change take place that the tadpoles never have a chance to grow to their full size and the frogs that result are unusually small.

How does thyroxin get into the blood? Thyroxin is secreted by the *thyroid gland,* a small gland about two inches long in man. As the cells produce the hormone it passes by osmosis directly into the blood in the capillaries. Then it is carried to all other parts of the body. Glands that produce hormones are called glands of internal secretion, or, more briefly, *ductless glands* or *endocrine* (en′doh-krin) *glands.*

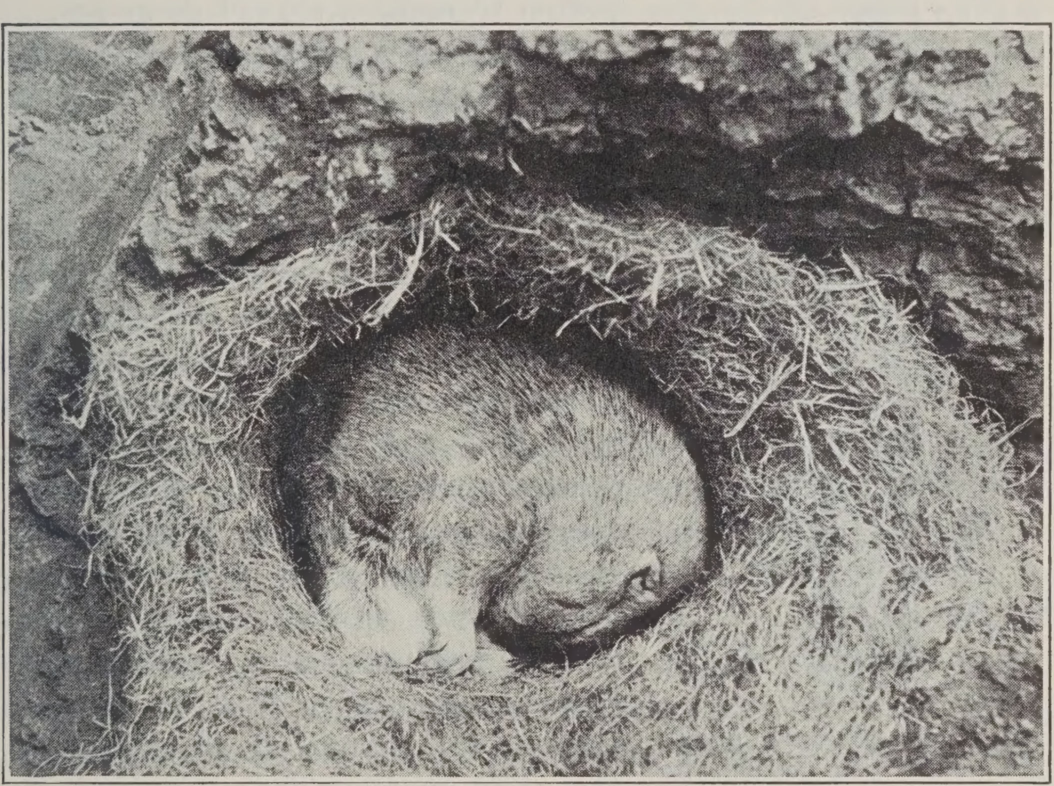


Photo by A. D. DuBois

Fig. 222. This ground squirrel was in hibernation six feet underground when its hole was opened. Can you explain why the rate of oxidation is low in a hibernating animal?

Scientists have discovered the formula of thyroxin and have actually made it in the laboratory. It contains besides the four elements common in living things comparatively large amounts of iodine. When a person does not get enough iodine in his food and drink it is sometimes necessary to feed iodine to the body.

In some individuals the thyroid gland is overactive or oversized and then an unnecessarily large amount of thyroxin gets into the blood; in others, it is not active enough or not sufficiently developed. In some persons, too, the gland may be normal in early life and change later. *Exercise 1.*

How can abnormalities in the thyroid gland be dealt with? If you know the function of thyroxin you can sometimes recognize the symptoms of an overactive or of an underactive thyroid gland in other people. But more frequently there are so many complications that the symptoms are not quite what you would expect. Only a physician may be expected to make a correct diagnosis.

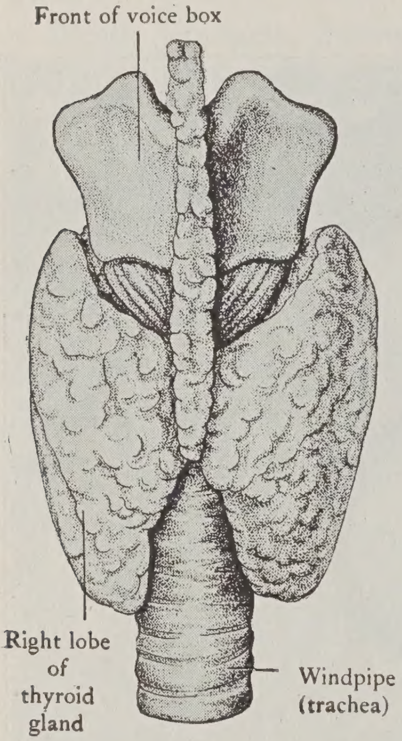


FIG. 223. Thyroid gland. How would you describe its position?

When a child is born with a thyroid which produces far less thyroxin than the body needs the condition of *cretinism* (cree′tin-ism) results. The brain and the rest of the body have no chance to develop as they should and a careful observer can soon notice that the child is mentally below normal, as well as undersized and underdeveloped. In cases like this thyroid extract from some animal can be given. If the treatment is begun at a very early age the child may show great improvement.

Sometimes, when the physical and mental development of a young child has been normal at first, an enlargement of the thyroid gland appears as the child grows older. Contrary to what you might expect, the gland, in these cases, is not overactive, but underactive. It is unable to secrete enough thyroxin, and perhaps to make up for this it increases in size, causing the neck to swell in the region of the gland. In any event, the cells of the body do not get enough thyroxin. The enlargement of the gland, known as goiter (goy′ter), occurs commonly in regions of the world where the amount of iodine salts in the drinking water or in nearby farm products is too small. Such goiter is said to be *endemic* (en-dem′ik), which means that it is characteristic of a certain region. The health officers in such localities sometimes add iodine salts to the drinking water, but this should not be done by a family except on advice of a physician.

Sometimes the thyroid gland secretes in normal amounts until after the person has become an adult and then begins to produce too little thyroxin. Since the rate of oxidation is below normal such a person tends to become overweight, his mental activities are slowed up, and he suffers from sensitiveness to cold. The thyroid is so extremely powerful in its effects that only a competent physician can prescribe treatment for such a condition.

In some cases the thyroid gland causes trouble because it increases in size and is overactive. The cells of the body receive too much thyroxin and the rate of oxidation increases. Such persons are restless and easily excited. In more severe cases, the patient loses weight, the temperature is above normal, and the heart beats more quickly than usual. A swelling of the gland or goiter forms but it is quite unlike the endemic goiter in which too little hormone is produced. This type of goiter, associated with too much secretion, often causes the eyes to bulge. If the condition is allowed to grow worse the life of the patient may be in danger; the amount of thyroxin produced must be reduced. There are several ways of doing this; shutting off the blood supply to part of the gland may help; if necessary, part of the gland is removed.

What leads physicians to suspect an excess or partial lack of thyroxin? If, in the metabolic activities of the body, the building up of protoplasm goes on faster than the using up of cell materials in oxidation the body grows larger; if oxidation goes on faster than the replacing of cell materials the body grows thinner. Since oxidation uses up oxygen and produces carbon dioxide the rate at which it goes on can be readily detected.

The apparatus that is used is fitted over the nose and mouth so that the amount of oxygen taken into the body and the amount of carbon dioxide given off can both be measured; there are tanks which supply the oxygen and catch the carbon dioxide. Such measurements have been taken for thousands of men and women so that physicians now know about how much carbon dioxide should be given off by a "normal" person of a given weight who is resting quietly. The rate of oxidation during complete rest is called the *basal* (bay's'l) *metabolism*. If a test of the basal metabolism of a person shows that the oxidation is far below the normal rate, the physician may conclude that the thyroid gland is not producing enough thyroxin. If the rate is far too high and there are other symptoms that point in the same direction the physician can conclude that the thyroid is overactive.

How is the use of sugar by the cells controlled? When a person steadily eats large quantities of carbohydrates some of them are changed to fat and stored in various tissues, especially under the skin; the person grows stouter. But normally all active cells need sugar, for the release of energy comes largely through the oxidation of sugar. As this carbohydrate is digested in the small intestine it is absorbed by the blood and carried to the liver. If the body is in immediate need of sugar it passes right through this organ and is swept along in the plasma and lymph. If not, the liver may take some of the sugar and store it in the form of an insoluble carbohydrate known as glycogen. When the muscle cells are oxidizing actively again and using up the sugar brought to them by the blood and lymph the supply in the blood becomes low. Then the glycogen is taken out of storage, changed back into usable sugar, and returned to the blood for distribution. Thus the normal body keeps the amount of sugar in the blood constant.

It is now known that all this sugar metabolism is regulated by a hormone in the blood known as *insulin* (in′su-lin). The insulin regulates the storage of sugar in the liver and also makes it easier for the body cells to use this carbohydrate. In other words, insulin prevents an oversupply of circulating sugar, no matter how much carbohydrate may be eaten. When not enough insulin is present, sugar accumulates in the blood.

The presence of a little more or a little less sugar in the blood may seem unimportant to you but any unbalancing of this sort may have far-reaching and serious effects. It is true that some of the extra sugar is removed from the blood by the kidneys but this does not remedy the trouble. The presence of sugar in the urine is a symptom of diabetes (dy′a-bee′tees), a disease which, if unchecked, may prove fatal.

How was the relation of insulin to sugar metabolism discovered? In the time of Nero diabetes had already been given a name and its symptoms described so carefully that the disease can be identified. But not until the beginning of this century did biologists learn the cause of the disease: the lack of sufficient insulin in the blood.

For a long time physicians thought diabetes was a disease of the kidneys because sugar appeared in the urine. Some time before 1850 the great French physiologist, Claude Bernard, a pioneer in experimental biology, studied this problem. He was not satisfied with speculation and observation as methods of solving the problems of medicine. Instead, he performed carefully controlled experiments on animals. By means of some of these experiments he showed that the liver takes part in sugar metabolism. Thus Bernard arrived at the conclusion that it might be the liver, rather than the kidneys, that was at fault in diabetes. However, experiments performed to prove the truth of his theory failed. He could produce no evidence that it was not the kidneys that were responsible.

More time passed, until in about 1890 an important discovery was made; and it was made, as so often happens, purely by chance. Many such discoveries are probably lost to the world. But in this case, fortunately, there were scientists who were prepared to fit this chance discovery into its right place. Two German investigators were interested in digestion, particularly pancreatic digestion. They had in their laboratory some dogs from which the pancreas had been removed. The laboratory helper who cared for the animals, a keen observer though knowing little science, noticed that the excretions of the dogs that lacked a pancreas attracted large numbers of flies. He reported this seemingly unimportant observation. The trained scientists, knowing that flies are attracted to sweet liquids, suspected that the excretions might contain large amounts of sugar. When this proved to be the case they reasoned that the excretion of sugar by an animal, contrary to all beliefs, might have some connection with the loss of the pancreas. Experiments were planned and performed. It did not take long to convince the world that disease or loss of the pancreas resulted in an oversupply of sugar in the blood and urine.

In the mean time, a biologist named Langerhans had discovered little patches of cells in the pancreas that were different in structure from the rest of the gland. It was suspected that these cells might have something to do with the work of the pancreas in controlling sugar metabolism. When examination showed that in the diabetic many or all of these cells were damaged, biologists were even readier to accept this belief.

The next step was taken by experimenters who cut the duct of the pancreas so that its digestive enzymes could not reach the small intestine. Despite this the animal did not get diabetes. By this time the fact that ductless glands exist had been established by the experiment on secretin so that it was easy to accept the idea that Langerhans's "islands" of cells were parts of a ductless gland which happened to be closely associated with the digestive gland cells.

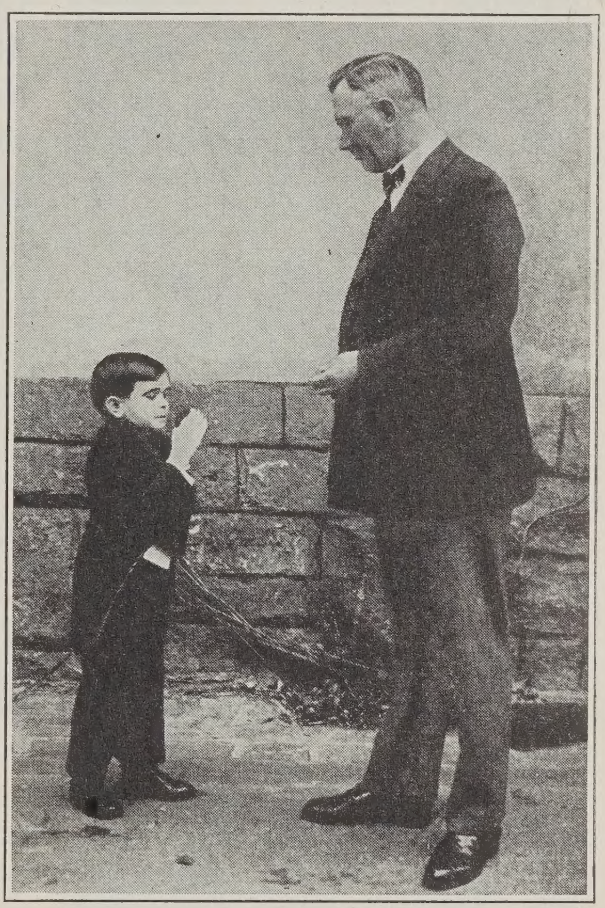
For a long time thereafter no one was able to obtain the hormone that this ductless gland secreted. It was not until 1921 that two Canadian physicians succeeded in obtaining the hormone of the pancreas. They called it insulin. Having learned that the pancreas makes insulin and that insulin is necessary for normal sugar metabolism, these scientists soon discovered ways of injecting this important hormone into the body of a human being who cannot supply his own. But this magnificent success has not ended the work on diabetes or insulin.

What can be learned about ductless glands from a study of circus freaks? The giant and the dwarf, the fat man and the bearded lady in the side shows of the circus are all individuals suffering from an abnormal condition of one ductless gland or another. More frequently still a disturbance in one gland has affected some other, making trouble all along the line; the ductless glands seem to influence one another constantly. In the cases that find their way to the circus the disturbance is so great that the outward changes become extreme. Many people have similar gland disturbances but fortunately they are less severe or they may have been checked at an early stage.

A person who grows to be seven feet or more is suffering from overactive gland cells situated at the base of the brain. Here lies the *pituitary* (pi-tew'i-ter-ree) *body*, a ductless gland about as large as a pea. It consists of three parts, the front one of which pours into the blood stream a hormone that speeds up growth of the skeleton. When too little of the hormone is produced in a child, growth of the bones is stopped so that a midget is produced; when it is too plentiful, giantism (gigantism) is the result. In cases of undersecretion extracts of the pituitary gland are injected but successful treatment is not common.

In some cases the rate of secretion of the pituitary is normal in childhood and youth but too great later on. In such cases, the skeleton as a whole is not changed, because full growth had been attained. But the extremities, the hands, the feet, and the bones of the face, then continue to increase in size. This condition can be relieved by operating on the gland.

In what other ways does the pituitary gland affect the body? There is a type of muscle found in the internal organs of the body which is unlike the muscle of arms and legs and back. This is muscle over which you have no direct control; it does not contract to order as does the muscle of your arm. But it obeys a hormone from the posterior (back) part of the pituitary gland. Such organs as the bladder and intestine have this type of muscle in their walls. When the hormone is sent into the blood these and other organs contract more violently than usual. Another hormone from the posterior part of the gland raises the blood pressure. And apparently there are still other hormones whose exact function still has to be worked out.

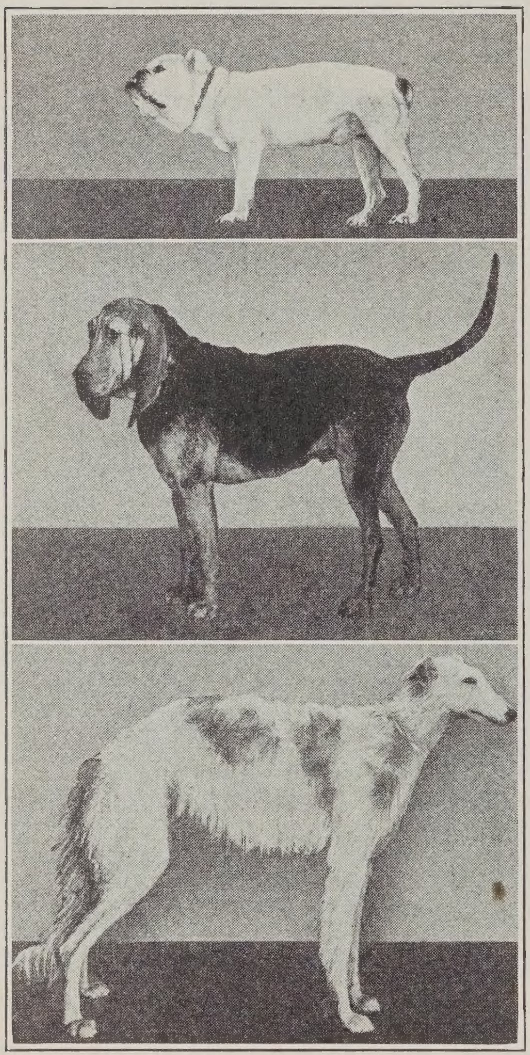


Copyright Pictures, Inc.

FIG. 224. Both men are full-grown. Why did the midget (dwarf) stop growing earlier than the man of normal size?

Studies of the pituitary gland show that it affects all the other ductless glands. Many scientists have decided, therefore, that it is a "master ductless gland." Its hormones help to determine how effective the other endocrine glands will be.

How can a hormone help the body adjust itself to emergencies? Fitting like a little cap on the upper end of each kidney lies a small mass of tissue (Fig. 218) which secretes a hormone, *adrenin* (ad-ren'in). Fear, anger, or excitement of any kind stimulates these glands so that adrenin enters the blood and is quickly carried around the body. Adrenin acts almost instantaneously and to see its effects you must look at all parts of the body at once. The skin becomes pale and, were the body transparent, you would see the internal organs losing color, too, for much of the blood is sent away from these parts. Instead, the blood flows freely into the large muscles and the brain. Meanwhile the digestive tract has largely stopped its activities; you would see no peristalsis and no secretion here; the heart, on the other hand, is beating forcefully. The air passages have widened so that now more oxygen reaches the lungs and, thus, the hemoglobin of the blood. The liver is giving up its stored glycogen to the circulation. The blood becomes changed in still another way; if allowed to escape it now coagulates more readily. And all these things occur within a few seconds.

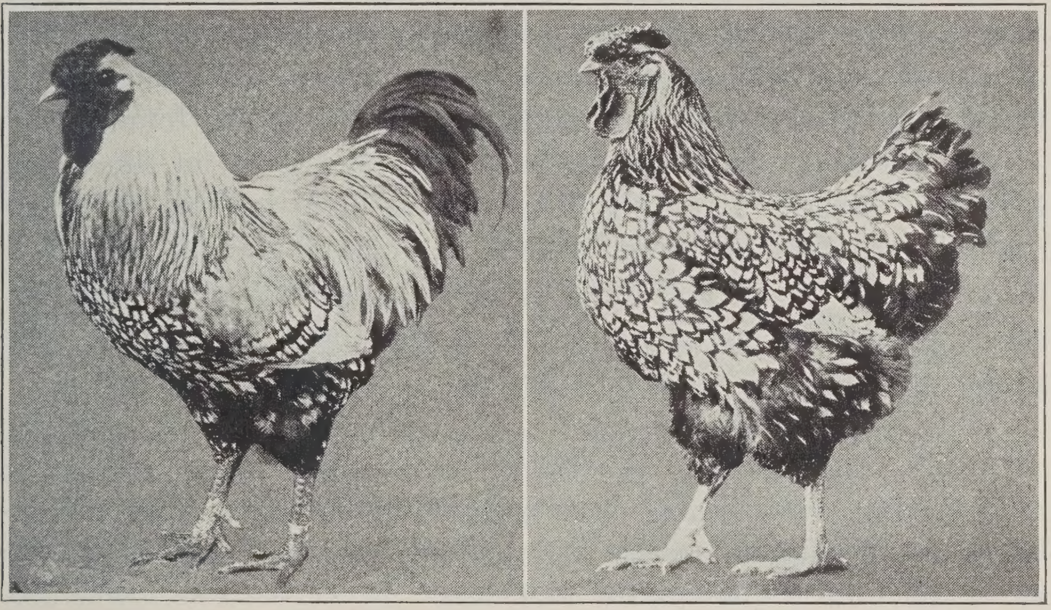


Courtesy Am. Mus. Nat. Hist.

FIG. 225. Ductless glands have an important effect on the structure of the body. Explain how the differences between the Russian wolfhound, bloodhound, and bulldog may be caused.

The body thus changed by adrenin is ready for an emergency. All provision has been made for oxidation and release of energy in the brain and in the muscles. The body has even been insured against too great bleeding. For this reason one biologist has called the *adrenal* (ad-reen′al) *glands* the "glands of combat." It is interesting that the adrenal glands, which can affect the body in this particular way, should secrete actively only when such emotions as fear or great joy are aroused. When the emergency is over the glands quiet down. To what extent they secrete at all times is not known; at best it is in small amounts.

In the sixteenth century the adrenal bodies had been discovered and been named but no one knew what they did. Bit by bit over a period of several centuries the mystery was cleared up. It has been known for a long time that death follows removal of the adrenal glands; it has been known, too, that the gland has two main parts, an outer and an inner. Recently it was discovered that it is the outer part which secretes a substance necessary for life; the inner produces the adrenin of which you have just read.



Courtesy U. S. Bureau of Animal Industry

FIG. 226. The sex glands of this silver-laced Wyandotte rooster (on the left) were removed. As a result he changed into the hen-feathered bird shown on the right. What is the difference in plumage?

Adrenin is like the other hormones in that an extremely small amount will produce an astonishingly great effect. It has been calculated that to reduce an ounce of adrenin to a point where its effects could not be observed when injected into the body it would have to be dissolved in as much water as would fill 10,000 water tanks, each holding six hundred and twenty-five gallons.

Physicians make frequent use of the powerful effects of adrenin on the body. As *adrenalin*, a commercial preparation, it may be injected into patients who are about to undergo operations. In cases of heart failure, it may even be injected directly into the heart in order to stimulate it.

What other organs serve as ductless glands? In close contact with the thyroid gland are the *parathyroids*. The secretion from the parathyroids seems to have something to do with the use of calcium by the body. When there is too little secretion there are too few calcium salts in the blood. Muscular cramps or convulsions occur as a result of this.

There is a gland, the *thymus* (thigh′mus), lying over the breastbone, which is large in childhood but grows smaller later. The thymus seems to affect growth in the child.

The sex organs, of which you will read more in a later unit, secrete hormones into the blood besides performing their function of reproduction. These hormones are of importance in developing the characteristics that distinguish the male from the female.

Year by year new hormones are added to the list of those you have read about. It may well be that as investigation continues other organs may be found to serve as ductless glands. This is a field which is recent and much research must still be done before scientists can understand how the complex activities of the cells in all parts of the body are regulated.

Exercises

1. How does the feeding of extracts of thyroid gland affect the development of tadpoles? Place a *very minute* amount of thyroid extract in an aquarium containing the tadpoles. Change the water each day before adding fresh thyroid extract. Observe and record what changes take place in the tadpoles. What control will you use in this experiment?

2. It is not difficult to obtain specimens of some of the endocrine glands from your butcher. Touch or handle the glands. How does gland tissue differ from muscle tissue? What is the color? Why are large amounts of blood necessary to the gland cells?

Problems for Classroom Discussion

1. Prepare a table of metabolic activities, putting in one column all those activities which are constructive, anabolic; and into the second column all those activities that are destructive, catabolic.

2. Endemic goiter almost always occurs in regions far from the sea. Can you explain this? What can be done to help people inhabiting these regions?

3. Because endemic goiter occurs in regions where it is known that the drinking water lacks iodine, is it reasonable to draw the conclusion that the goiter is caused by the lack of iodine? Suppose that someone advanced the theory that endemic goiter was caused by a microorganism. How might you find out which hypothesis is correct?

4. Would an oversecretion of thyroxin tend to make a person more intelligent? Explain.

5. Some types of pills designed to reduce weight have been found to contain relatively large amounts of thyroxin. Would these pills help to reduce weight? Explain. Would it be wise to take such pills without a physician's advice? Why?

6. Explain why shutting off the blood supply from the thyroid gland would help a person suffering from an overactive gland.

7. The account of the discovery of insulin is more or less typical of all important scientific discoveries. Read the paragraph again carefully. How many centuries did it take before there was more real progress in solving this problem? Why did it take so long? Do you think that the laboratory helper was using any of the methods of science? Explain. Why were the scientists able to make use of this accidental discovery? From what you have just learned, sum up as many elements of scientific method as possible. Then list the qualities which a good scientist must possess, and in each case refer to a definite incident as an example.

8. What truth is there in the statement: "Experimentation speeds up a hundredfold the acquisition of knowledge"? What is there peculiar to an experiment that enables a scientist to get at the truth more quickly?

9. Think of the various breeds of dogs that you have seen (or study pictures of different breeds) — such as, the Great Dane, wolfhound, bulldog, Pekingese, etc. These dogs have been bred because their gland abnormalities produce such striking forms. Can you state what gland is functioning abnormally in each case?

10. How can you explain the fact that in an emergency a person can sometimes perform unusual feats of strength?

11. Summarize all of the important facts that you have learned about the regulation of sugar metabolism.

12. *Summary.* Make up a table that will contain all the essential facts about glands studied in this problem. What headings will you use?

Activities for the Junior Biologist

1. Look up the story of the discovery of secretin. Report to the class.

2. Deliver a lecture to your class or club on circus freaks. You can make your talk more entertaining by illustrating it with pictures.

3. Much has been written about the effect of the endocrine glands upon personality. Look up and report to the class on this topic. Be very critical of this work.

4. Plan other experiments like Exercise 1. Consult your teacher before attempting them.

Problem 5. How Does the Higher Plant Supply the Needs of Its Cells?

How do the needs of plant cells compare with those of animal cells? A plant cell has a cell body and a nucleus; it needs the same substances for assimilation as does an animal cell. To manufacture these substances it needs large amounts of carbon dioxide, water, and minerals. Every living plant cell, too, releases heat energy. For this reason it must be supplied with oxygen. But in the plant oxidation is less rapid on the whole, for the plant lacks the actively oxidizing muscle cells of an animal. So that, while the plant cell requires oxygen, it needs it in much smaller amounts. And since oxidation in most plant cells goes on much more slowly than in animal cells the problem of the disposal of wastes is a simpler one. Besides this, in all but a very young and rapidly growing plant there are many dead cells which need not be supplied with food and oxygen nor be relieved of wastes. The plant faces a simpler problem than the animal when supplying the needs of its cells.

How does the higher plant obtain the necessary oxygen and supply it to all its cells? Since there is so much less oxidation in a plant no special device like hemoglobin carried by a rapidly moving blood stream is necessary. And since the oxygen is not carried in a blood stream no large scale breathing organ like the lung is required, either. Instead, the plant has simple openings — stomata on leaves and lenticels on stems. The oxygen that enters here diffuses throughout the plant.

The epidermis of the root has no stomata. But all the younger roots are covered with thin-walled cells, and oxygen dissolved in soil water enters these. That root cells are really dependent on this supply of dissolved oxygen is shown by the fact that plants which are grown in soil which is not properly aerated (mixed with air) fail to grow well. The farmer knows this and tries to keep the soil around his crops cultivated or broken up into small particles because in this way air is mixed with the soil. In raising potted plants it is important to have proper drainage at the bottom of the pot otherwise the soil will be soaked with water and thus be unable to hold the necessary air. Even though the cells need only small amounts of oxygen they must be steadily supplied with it, both through the leaves and through the roots. *Exercise 1.*

How does the plant dispose of the wastes formed by oxidation in the cells? As in the animal cell, the wastes formed in the plant cell by carbohydrate or fat oxidation are carbon dioxide and water. Both these gases (for water is in the form of vapor) diffuse through the continuous air spaces and in time go out through the stomata and lenticels. When substances other than carbohydrates are oxidized, nitrogenous mineral compounds are formed as well as water and carbon dioxide. Such compounds can frequently be used over again by the cell in the synthesis of new proteins. In a few cases wastes are built into the cell wall, where they remain. You can see that the plant no more needs large scale excretory organs to get rid of the wastes formed by the many cells than it needs large scale breathing organs or digestive organs to provide enough oxygen and food for its cells.

How do photosynthesis and oxidation affect the intake and outgo of gases? In respiration oxygen unites with carbohydrates; carbon dioxide (and water) is formed by the cells. The reverse of this takes place in photosynthesis: carbon dioxide is used in the production of carbohydrates, and oxygen is formed.

During the day, since photosynthesis goes on much more rapidly than respiration, whatever carbon dioxide is formed as a result of oxidation is promptly used in photosynthesis; carbon dioxide leaves the plant, therefore, only from those parts that lack chlorophyll. And the oxygen needed for oxidation can be obtained from the comparatively large amounts of oxygen given off as a result of photosynthesis; most parts of the plant need not take in oxygen. At this time, therefore, the plant is taking in carbon dioxide and giving off oxygen. At night, when photosynthesis does not go on, the intake of oxygen and the outgo of carbon dioxide can be readily detected.

How does the system of transportation in the plant differ from that in the animal? You have just read that the oxygen transports itself by the simplest, though not the most rapid, method: diffusion from the surrounding atmosphere to the individual cells. Carbon dioxide and water vapor travel by the same method in the reverse direction. The other wastes are unimportant. Therefore, transportation in the plant is largely the transportation of raw materials from the root hairs to the manufacturing cells in the leaves or stems, and later the carrying of manufactured products from these green cells to other colorless cells which use up or store the synthesized foods. There are two distinct currents of liquids in a plant, one up and one down. In other words there is no real "circulation" as in an animal; there is merely conduction.

How are the necessary raw materials transported from roots to leaves? Microscopic examination of root and stem and leaf shows the presence of long, narrow tubes known as *ducts*. Each duct is a row of cylindrical cells, piled end to end, with the end walls dissolved away so that a continuous tube of considerable length is formed. The protoplasmic contents disappear early in the formation of the duct, leaving nothing but the dead cell walls. These become thickened with a woody substance (*lignin*) which is laid down in various designs, sometimes in rings like barrel hoops, sometimes in spirals, or in still other forms. Among these ducts are other cells which are also dead and empty; they too have thickened, decorated walls. But when they grow one above the other their end walls do not disappear; each cell remains distinct from the other. Water with its dissolved minerals travels up through both kinds of channels in the true flowering plant; in the evergreens, the ducts are lacking and soil water is conducted entirely through the short cells (known as tracheids). Under normal conditions large quantities of soil water are absorbed by the plant and transported; as long as the leaves remain on the plant there is a steady upward flow. *Exercise 2.*

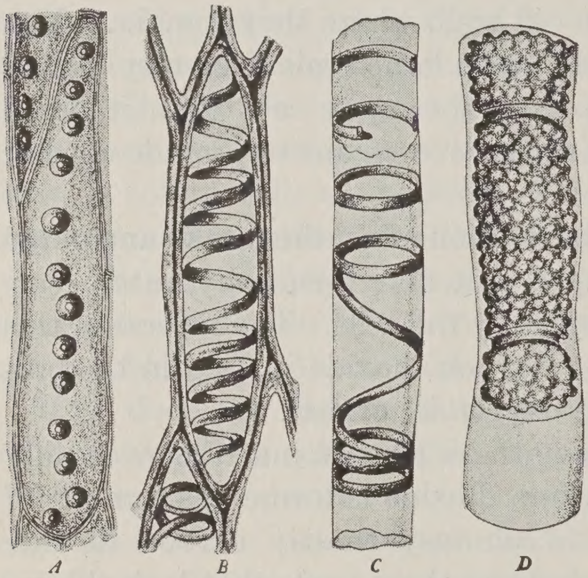


FIG. 227. Conducting Tubes. *A* and *B* are tracheids; *C* and *D* are ducts. What are the various kinds of thickening shown?

What force makes the soil water rise? When water enters the root hairs of a plant by diffusing through the membrane of the cell, a force is exerted that is known as *osmotic pressure*, or *root pressure*. That this pressure exists can be shown by the thistle tube experiment in which the water that enters the thistle tube rises for one or more feet in the tube against the force of gravity. Recently it was discovered that root pressures may be very great, so that it is possible that water is pushed up to the tops of even tall trees by this force. *Exercise 3.*

In their search for other forces that might push the water up the ducts biologists studied *capillary action.* This occurs only in very narrow tubes, called capillary tubes. If you dip such a tube into water the water will rise in the tube. The narrower the tube the higher will the water rise against the force of gravity, but there is a limit to the height to which the liquid will rise in even the narrowest tubes. The ducts in plants are capillary tubes. It is believed, therefore, that capillary action takes place in them. But capillary action does not explain how water can reach the leaves at the top of a tree which may rise one hundred, two hundred, or even three hundred feet above the ground. *Exercise 4.*

Within the last thirty years, another force also has been discovered that may help to explain the rise of columns of water through even the tallest plants. It was discovered by scientists who were studying the way in which a very narrow column of water acts. They found that the water in such a column stayed together as if it were a wire. If some kind of pull could be given at one end the whole column moved; if the pull was strong enough the column moved against the force of gravity.

Just such a pull exists in plants. It is the evaporation of water out of the stomata of the leaves. This goes on all the time. It provides the sort of pull that acts on the water in the narrow ducts all the way up from the roots.

The explanation that water is being pulled up in a continuous column is not wholly satisfactory in all cases since some of the tubes in plants are not continuous. In these cases root pressure and capillary action probably do the work. There may be forces that have not yet been discovered. *Exercise 5.*

What becomes of the soil water that is pushed and pulled up through the ducts? Under normal conditions there is a steady and plentiful flow of water in the root hairs and up through the ducts of root, stem, and leaf. As this water passes the active cells the dissolved mineral compounds are taken out for protein synthesis. When this water reaches the starch-making cells only a small part of it is used for photosynthesis, sometimes less than one per cent. The rest of the water is carried to the surface of the leaf or young stem, from which it evaporates through the stomata or lenticels. This evaporation is much like the evaporation that occurs from your body but it has a special name, *transpiration* (tran′spi-ray′shun).

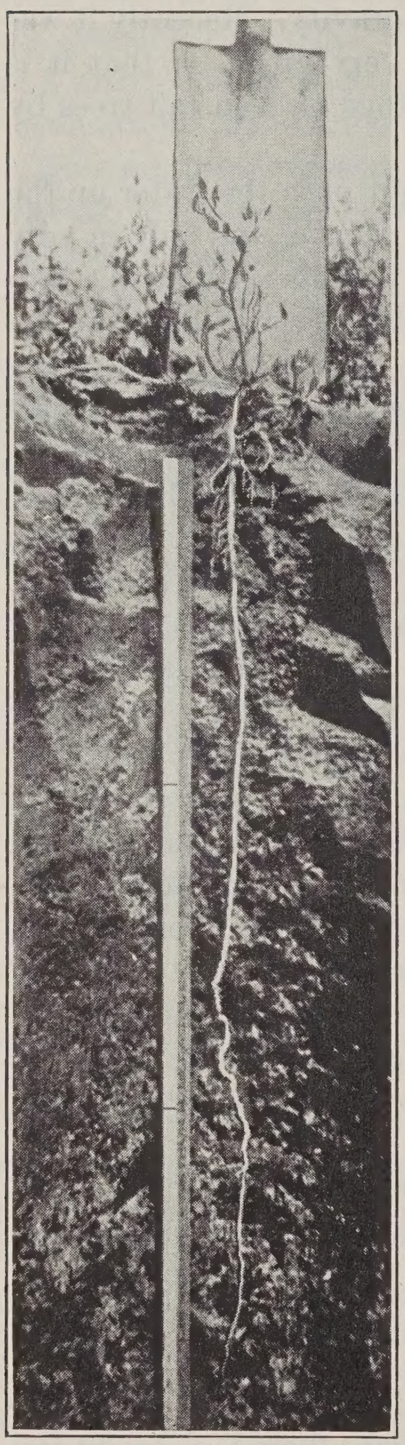

Ill. Ag. Exp. Sta.

FIG. 228. How does the length of the root compare with the height of the plant? Of what advantage is this long root?

Since the size of a stoma is regulated by the guard cells the guard cells can regulate the rate at which transpiration goes on. It has been discovered by experiment that the loss of water by transpiration from a living plant is less than the loss by evaporation from a dead plant. But the guard cells cannot close the stomata completely and stop all transpiration. A birch tree that gives off sixty to seventy quarts of water a day may lose five times that amount if the day is hot and dry; despite the closing of stomata evaporation goes on rapidly. *Exercises 6, 7.*

Water is needed not only for photosynthesis and for the carrying of dissolved substances but also to help hold up the leaves and stems in which there is little woody tissue. If there is enough water in the plant the cells are swollen with water so that their cell membranes are stretched. This makes the cells, and therefore the plant, firm and rigid. If the plant does not have enough water it droops and is said to be wilted. *Exercise 8.*

The plant must at all times have large amounts of water but it is interesting that in order to obtain water it must continually give it off. For transpiration is an important force that enables the plant to keep water moving up from the roots to the leaves.

In what ways is transpiration important to man? To man, transpiration in the plant is of extreme importance not only indirectly in making the life of land plants possible but more directly in providing rain. If a single birch tree with about 200,000 leaves can transpire as much as 350 quarts on a hot, dry day the thousands of trees in a forest must add enormously to the water vapor in the air. There would be far less rainfall if plants kept water locked up in themselves instead of maintaining a steady transfer of water from the soil to the air. When, by means of irrigation, plants other than native, water-hoarding desert plants are enabled to grow in considerable numbers in dry regions, the rainfall is promptly increased; not only because water evaporates from the ditches but also because the plants send large quantities of it into the air. In this and other ways large forests actually cool the surrounding territory.

U. S. Forest Service

FIG. 229. If a cabbage leaf has 11,000,000 actively transpiring stomata, how many might this American elm have?

How do manufactured products travel down through the plant? In the preceding paragraphs you have read how soil water is moved up to the green parts of the plant where photosynthesis takes place. These cells can supply themselves with manufactured foods. But there are many cells in the root and the inside of the stem that lack chlorophyll and are never reached by light. They, too, need manufactured food. There are often regions, too, far from the leaves, where food is stored. These may be roots or special underground stems enlarged for storage. Clearly, there must be special ways of sending sugars and proteins down through the plant; they cannot travel easily through ducts which have a constant transpiration stream upward.

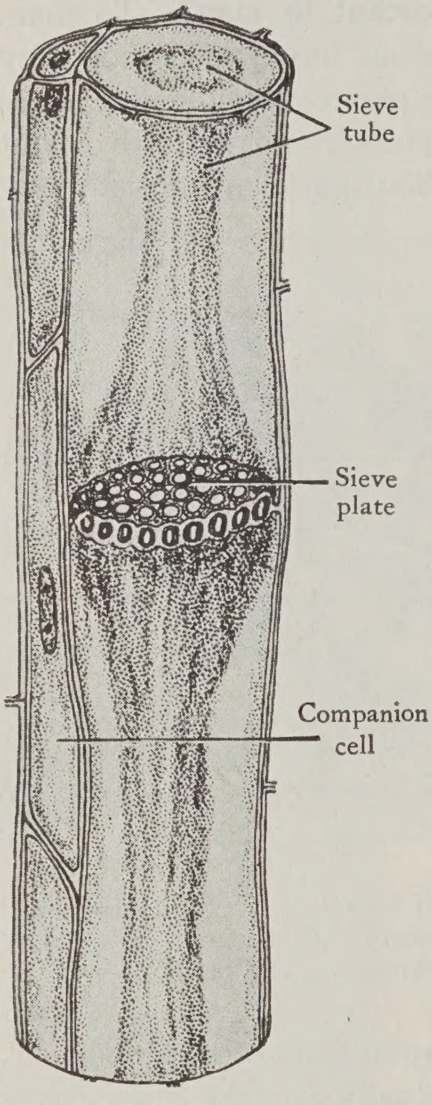


FIG. 230. The cells that form the sieve tube lack a nucleus. It is believed that the nucleus of the companion cell controls the neighboring sieve tube cell.

In older stems, manufactured foods are known to travel downward through the inner portion of the bark outside the wood while the soil water travels up through the woody region near the bark. If willow or poplar twigs, which readily form roots in water, are girdled just above the surface of the water (the bark is removed over a small area all the way around the stem) the leaves do not wilt, showing that the passage of soil water is not interfered with. But roots, as they begin to form, will come from the region above the girdling, not below. The manufactured foods in their downward course cannot get beyond the girdled part because they travel through the inner bark. You can see that removing a ring of bark from a living tree does more than make the tree unsightly. It keeps manufactured foods from reaching the cells of the root and thus eventually kills the tree. *Exercise 9.*

The structures in the inner bark through which foods travel down are *sieve tubes*. A sieve tube is a row of long narrow cells which, unlike the cells making ducts, remain alive. Holes appear in the walls at the top and bottom of each cell so that the ends look like sieves. Strands of cytoplasm pass through these pores from one cell to the next. Since the sieve tubes are not hollow, substances do not drop down them; they must pass down by diffusion.

What does a section through the root and young stem show about the distribution of conducting tissue? In the young root, sieve tubes and ducts lie close to the center within a region known as the *central cylinder*. In the young stem the conducting cells are gathered together into small groups or bundles arranged in a circle within the stem. In some cases there are no more than five or six bundles; in other cases they may be much more numerous. Each bundle runs up through the stem and into the leaf where it is seen as a vein. The word for conducting is *vascular* (vas′kew-lar), so the bundles of sieve tubes and ducts may be spoken of as *vascular bundles. Exercises 10, 11.*

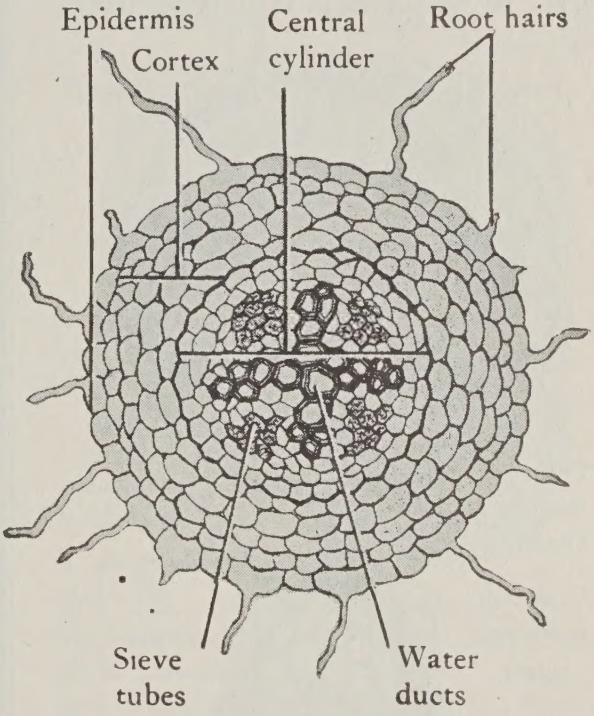


FIG. 231. Cross section through a root. What region is found directly inside the epidermis? In which region do you find sieve tubes and ducts?

Since these vascular bundles contain tough fibers among the conducting tubes they are called *fibrovascular* (fy′bro-vas′-kew-lar) *bundles.* The fibers are enormously lengthened cells; one fiber may be ten inches long. The protoplasm within the fiber dies and the cellulose walls change into extremely elastic and tough material. This fits them for giving support to the stem. Such fibers are also found among the ducts and the sieve tubes in the root. They become more numerous in an older root or stem and give it increasing strength. *Exercises 12, 13, 14.*

What becomes of conducting tissue in an older stem? Since the stems of herbaceous plants live only for a year they do not change. The stems of trees and shrubs live for many years; as time goes on these stems change so that the older stem is different from the younger. As the plant grows older the stem develops a tougher bark and the inner part of the stem becomes filled with a substance called wood. The way in which a strong woody stem covered with thick bark develops from the young stem described above is so complicated that it need not be told in detail. But the change in the arrangement of conducting and supporting tissue as the stem grows older is important.

In the young stem these tissues are in separate fibrovascular bundles, arranged, in the dicot stem, in a ring, as described above. In the first few years of the stem's growth the cells between the fibrovascular bundles change into new supporting and conducting tissue so that the fibrovascular bundles are closer to one another. In time, the separate bundles disappear and there is a complete ring of supporting and conducting tissue, the sieve tubes being on

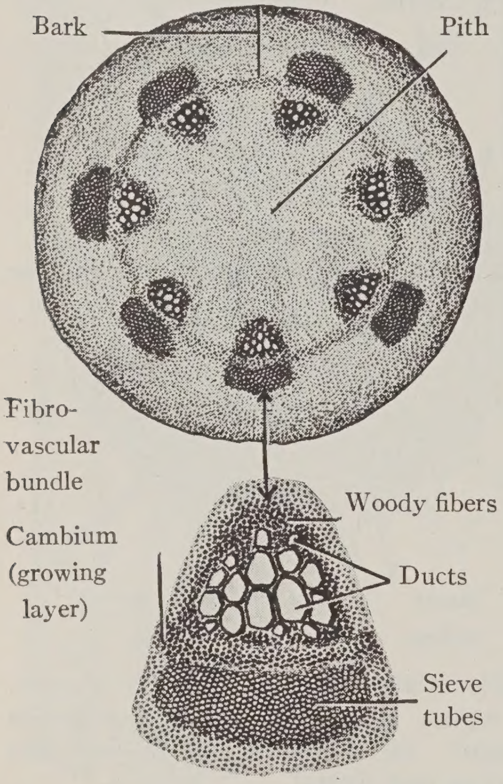
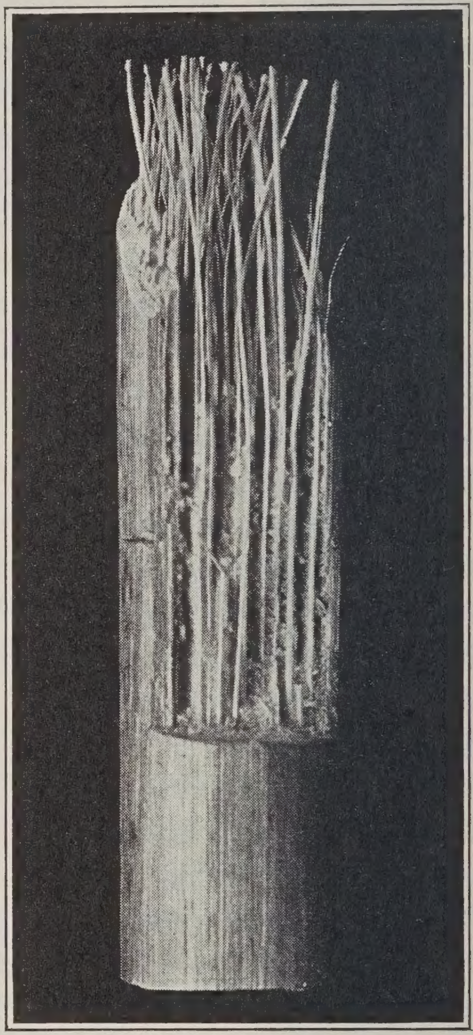


FIG. 232, *a*. Cross section through a young dicot stem. What proportion of the stem is conducting tissue? The thin-walled pith cells are well adapted for osmosis. Liquids can travel through them across the stem.



© *P. Blakiston's Son & Co., Inc.*

FIG. 232, *b*. This shows the fibrovascular bundles in a monocot stem. How do they compare in position with the bundles in a dicot stem, shown in the diagram at left? Do you see pith?

the outside (or bark side) of the ring and the ducts on the inner (or wood) side. Actually, the sieve tubes lie in the inner part of what is called the bark, and the ducts lie in what you think of as the wood. The supporting fibers are in among the sieve tubes and ducts.

The sieve tubes and ducts are separated from one another by a ring of thin-walled cells that are of the greatest importance to the plant. These cells never take on the characteristics of conducting or supporting tissue. They keep their protoplasmic contents and retain their power of active growth. They are called *cambium* (kam′bee-um) cells and the layer is called cambium. All the new supporting and conducting cells, which appear as time goes on, start as simple cells formed from the division of cambium cells; then they become differentiated.

Within these three cylinders of cells, sieve tubes, cambium, and ducts, in the very center of the stem, are the thin-walled cells of the *pith*. The pith cells remain unchanged. As the stem grows larger, strands or sheets of pith cells remain, cutting across the rings of conducting tissue. In a cross section of the stem these sheets of pith cells show as radiating lines, called *medullary* (med′ull-er′i) *rays*. Medullary rays are necessary for transporting substances across the stem into or out of the pith.

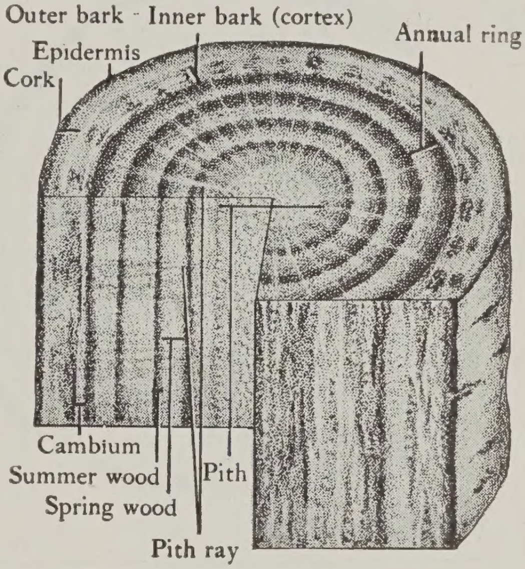


FIG. 233. Sections through an older dicot stem. In the cross section find bark, wood, pith, cambium (exaggerated to show its position). How does the spring wood differ from the summer wood? How old is this stem?

Since the actively growing region is the sheath of cambium, it is possible to discover how the stem grows and changes by studying the cambium cells for a whole year. At the end of the winter, when the ground thaws, water can again be absorbed by the roots and sap begins to flow upward. Then the cells of the cambium divide actively and form new thick-walled ducts and fibers toward the inside. At the same time they produce more of the sieve tubes and fibers toward the outside. The ducts formed in the spring of the year are wider cells than those formed in the late summer. Even to the naked eye the spring growth is thus clearly marked off from the summer growth. This is not true of the sieve tubes. Close study of the bark shows no difference between the cells formed in different seasons. A "ring" (cylinder) of wide and narrow cells is thus formed in the wood each year.

As the years go on, more rings of wood are continually being formed toward the inside; more bark toward the outside, even though here one ring is not distinguishable from the other. The bark soon begins to scale or split off. As the amount of conducting tissue is increased, the stem grows thicker. This growth in thickness is known as secondary thickening or *secondary growth.* While secondary thickening proceeds throughout the plant, stems and roots continue to grow at their tips.

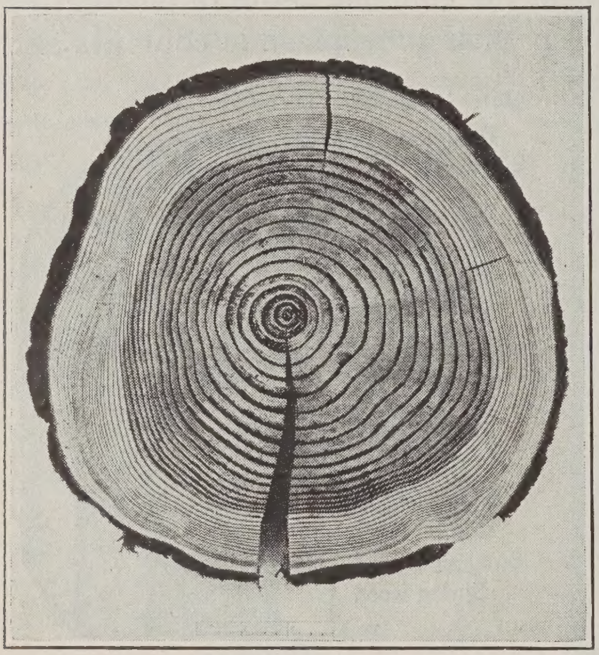


Photo by Prof. E. Fritz, Univ. of Cal.

FIG. 234. By counting the rings, you can find out how many times the cambium started up its growth; in other words, how many springtimes this tree has seen. The pith has been crowded out. The darker wood is *heartwood;* the sapwood (lighter wood) contains ducts that still function. Although new bark forms every year, the bark is thin. Can you explain?

In our part of the world trees and shrubs are either evergreens or belong to the group of flowering plants known as dicotyledons, those with net-veined leaves. They all have a woody stem and true bark and reveal their age by their rings of growth. The monocotyledons are represented only by small herbaceous forms. But in warmer parts of the globe there are many monocotyledons that attain the size of our trees. Their trunks, however, never develop rings of growth nor true bark. Throughout the life of the plant the fibrovascular bundles remain as distinct strands. A slight increase in thickness is obtained by the formation of new bundles. *Exercise 15.*

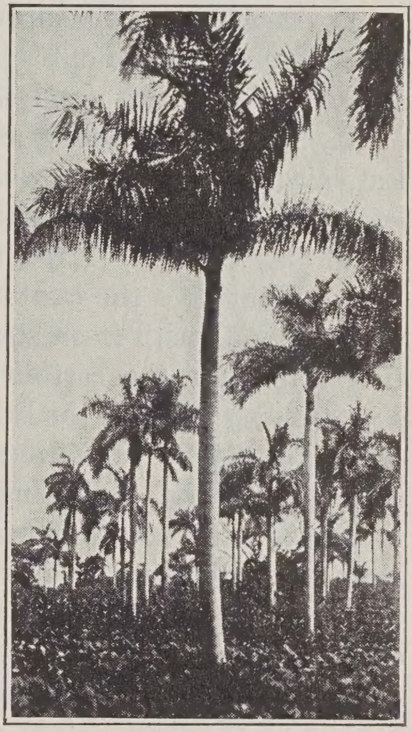
Exercises

1. How can you show that soil contains air? (Bubbles of air rise in water.)

2. What course do liquids take through the leaf and leafstalk? Place the lower ends of several fresh stalks of celery into a tumbler containing an inch or two of diluted red ink. Place in bright light. Observe at regular intervals. After several hours cut a stalk crosswise a slight distance above the surface of the liquid. Then cut the lower part lengthwise in half. Make a sketch of both sections, using red crayon for the parts which are colored by the ink. When the ink has reached the leaves of another stalk, hold it up to the light. Show in a diagram how soil water normally travels through the leaf. What kind of cells would you expect to find in the veins?

3. How can you show and measure root pressure? Use a plant with a stem at least $\frac{1}{4}''$ thick. Uproot carefully. While holding the stem under water cut off all but about 1″. Connect this to a glass tube by means of a short piece of rubber tubing. Support the roots in water. What do you see after some hours? Keep careful record of the amount of rise and the time. Put the plant into a weak sugar solution. Do you note any difference?

4. How does the narrowness of a tube affect the rise of water through it? Place hairlike glass tubes of varying thickness into colored water. What differences do you note? Make accurate measurements and record. With a magnifying glass examine the top of the column in the widest tube. What do you notice? Explain.



Brooklyn Bot. Garden

FIG. 235. Compare the trunk of this palm tree with the tapering trunk of a dicot tree. Why is this almost the same thickness from top to bottom?

5. Does a plant give off water? Use a vigorously growing plant that has just been well watered. Cover the pot and earth completely with a thin rubber sheet. Place the potted plant under a bell jar, in the light. What do you observe after a half hour and again after several hours? Are you ready to draw conclusions? What else should you do?

6. How much water is lost by an actively transpiring plant? If scales are available set up a plant as described in Exercise 5. For how long will you permit transpiration to go on? Why? Keep an accurate record of weights before and after. Discuss your method with the class before proceeding. Can you calculate the amount of water lost per square inch of leaf?

7. Through which epidermis is transpiration more rapid? Prevent transpiration from one surface of the leaf by coating it with a thick layer of vaseline. Measure the amount of transpiration by weighing. Now try the other side. Explain your results.

8. Does water help support the stem of soft-stemmed plants? Devise an experiment to find out. (*Hint.* Use seedlings.) Will your experiment apply to plants with woody stems? Explain.

9. How does girdling affect the stem? Use several willow twigs in leaf, girdling some and leaving some ungirdled. Remove most of the leaves. Place the twigs in the light but shut the light off from the roots which may develop. Explain the results.

10. What does the carrot show about root structure? If possible use young carrots with fresh stems and leaves. After cutting off the tips of the roots place the carrots in a tumbler containing red ink in water. After having stood in the bright light for several hours one of the carrots should be sectioned at various levels. Make a longitudinal section through a second. Draw, indicating by means of red crayon the regions where the ducts must be. Compare with the diagram of the root in the text. How does it differ? On your drawing label central cylinder, cortex, epidermis, ducts. In which region do the stored carbohydrates lie? How can you find out?

11. What is the structure of a young root? Gather some young fibrous roots about $\frac{1}{16}''$ in diameter. Scrape these with the fingernail. How does this substance feel? What is left when you have removed this substance? What could you call the part that is left? Try to break it and to tear it. What do you notice? Explain.

12. Where are the fibrovascular bundles in a young stem? After placing the soft stem of a herbaceous plant between two pieces of pith cut as thin a cross section as possible. Study it under the microscope and compare with the diagram. What differences do you note?

13. How does a monocotyledonous stem differ from a dicotyledenous stem? Cross and longitudinal sections of young cornstalks make good material for the study of fibrovascular bundles in a monocot stem with the naked eye. How many bundles are there in your cornstalk? Where are they? How do they feel? Describe the covering of the stem.

14. How does an older woody stem differ from a young stem? Cut cross and longitudinal sections of a twig two or three years old. Examine the outside of the bark. Describe its appearance. What important structures would you look for on the outside? Do you see them? Describe. With your nail or with the help of a dull knife remove the brown bark. How does the layer underneath differ from the brown bark? What might be its function? Does light reach it? Remove this layer. Do you find a colorless layer inside of it? Try to tear it. This is still part of the bark. Having removed the third layer of bark you see the wood inside. Feel it. How does it differ from the inner bark? Prick the inside of the stem with a pin. What do you find? Examine the diagram in the text. What layer did you fail to see? If you read the text you will know why you failed to see it and you will discover how the three layers of bark and wood were formed.

15. How does a stem grow in thickness? Copy this diagram of a longitudinal section through the pith and wood of a five-year-old sapling. The bark is not shown. At the bottom of your copy put the numbers 1 to 5 using 1 to represent the wood present when the tree started its existence.

Five represents the most recently formed wood. Draw a cross section at each of the levels *a, b, c, d.* Where ought you to cut the section to determine the exact age of a tree? What is the general shape of the trunk? Why? What do you notice about the thickness of the pith on top and at the bottom? Can you explain?

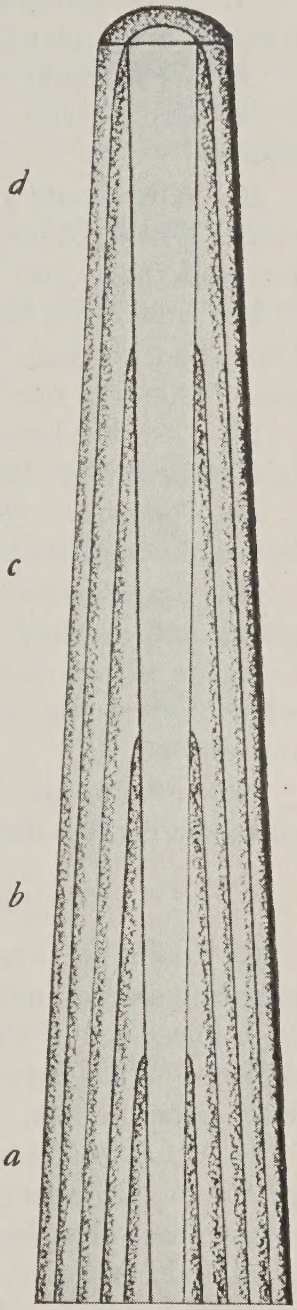


FIG. 236. Long section through 5-year-old stem.

Problems for Classroom Discussion

1. Why is the best flower pot one that is unglazed and has a hole in the bottom?

2. What is the underlying reason for the great differences between the structure of plants and animals?

3. Why is it unnecessary to remove plants from a sickroom at night?

4. Why could a plant not exist with one wide tube through the trunk instead of the many microscopic ducts?

5. Explain the statement "Transpiration increases with a larger amount of moisture in the soil, and the amount of moisture in the soil in time increases with transpiration."

6. What else besides the amount of moisture in the soil determines the amount of transpiration?

7. After watering it thoroughly what else might you do to help revive a wilted house plant?

8. What would you consider the best time for transplanting? Why?

9. Explain two ways in which a plant profits by its huge waste of water?

10. Why should you not twist wire around a young tree?

11. When you remove the bark from a twig why does the wood lying just underneath feel wet and slippery?

12. How can a botanist by studying a cross section of a very old tree know that the year 1750 in that particular region was a dry year and the year 1820 a wet one?

13. Does the lower part of a tree trunk show a greater annual increase in thickness when the tree is young or old?

14. *Summary.* Outline the problem, showing by the numbering and lettering which are the more important ideas, which the less important.

15. *Unit Summary.* You have read that respiration and excretion in plants and animals are different. In what respects are they different? Compare plants and animals also as to transportation tubes, the force which moves the substances, and the composition of the substances transported.

Now go through the first four problems and list the most important rules you can lay down to help keep yourself in good health.

Activities for the Junior Biologist

1. How much oxygen is used up by a sprouting seed? Place a germinating seed on moist cotton inside of a glass tube sealed on top. The open lower end of the tube should stand in a 4% solution of sodium hydroxide. What happens at the bottom of the tube as oxygen is used up? Keep careful notes.

2. Are all stems equally well fitted for sending water up? Compare geranium with celery. Use 6 or 8 stems of each kind. Cut the stems off under water and place in red ink. About every ten minutes cut longitudinal and horizontal sections of one stem of each kind. This experiment must be repeated. Why?

3. Could you show the lifting power of transpiration by using mercury? Use a leafy twig and speed up transpiration in every way possible.

4. Does light affect the rate of transpiration? Can you devise an experiment to find the answer? (Cobalt paper turns red when moist.)

5. How does temperature affect the rate of transpiration? You can use cobalt paper on a leaf or use a whole plant if you have scales.

6. Are epidermal cells completely waterproof? Some leaves, such as apple and barberry, have no stomata on the upper surface. You can close up all the stomata on the lower surface by using vaseline. Find out whether any transpiration goes on.

7. If willow twigs are available you can make a whistle and find out at the same time where the cambium lies. Gently pound a short piece of stem all around. Thus you can separate the wood from the bark and remove it.

8. If you have ever visited a lumber mill (or seen one in the movies) report to the class.

9. The graining in wood obtained by different methods of cutting is an interesting subject to look up.

Good Books to Read

Carlson, A. J. and Johnson, V., *Machinery of the Body*. Univ. of Chicago.
Clendening, L., *The Human Body*. Knopf.
Cockefair, E. A. and A. M., *Health and Achievement*. Ginn.
Goldschmidt, R., *Ascaris; the Biologist's Story of Life*. Prentice-Hall.
Harvey, W., *The Motion of the Heart and Blood*. Everyman's Library, Dutton.
Hegner, R. W., *College Zoology*. Macmillan.
MacDougal, D. T., *The Green Leaf*. Appleton.
Sinnott, E. W., *Botany*. McGraw-Hill.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life*. Doubleday.

UNIT VI. WHY DO LIVING THINGS BEHAVE AS THEY DO?

Problems

1. Why Do Protozoa Behave As They Do?
2. How Does the Behavior of Complex Plants Compare with That of Protozoa?
3. How Does the Structure of Many-celled Animals Enable Them to Receive Stimuli and Respond to Them?
4. What Kinds of Behavior Are Found in the Many-celled Animals?
5. How Are the Higher Animals Fitted for Their More Complex Behavior?

Problem 1. Why Do Protozoa Behave As They Do?

How do Protozoa behave? Professor H. S. Jennings, who has spent many years studying the behavior of Protozoa and of other simple animals, relates how he once sat for a long time over his microscope watching a large ameba pursue a smaller one back and forth across the slide. After a long chase the pursuer pinched off a small piece of its prey and attempted to wrap itself around the piece as it would do with any particle of food. But the small piece of ameba was alive and active and by sending out pseudopods managed to flow away from its captor. Again it was chased, and engulfed. Again it escaped. This time the large ameba stopped chasing the smaller one. But do not think that it gave up "in despair," for as far as we know, neither the large ameba nor the small one was in any way conscious of what it was doing. The small ameba was not "afraid" of its pursuer, nor did it "try" to escape or plan its actions. The behavior of both amebae was typical of that of any protozoan at all times. The small ameba was serving as a food *stimulus* (stim′you-luss) to the larger one; the larger reacted to this stimulus, or *responded*, by sending out pseudopods in the direction of the stimulus. The small ameba was also responding to a stimulus; its response was the forming of pseudopods which moved it in the opposite direction.

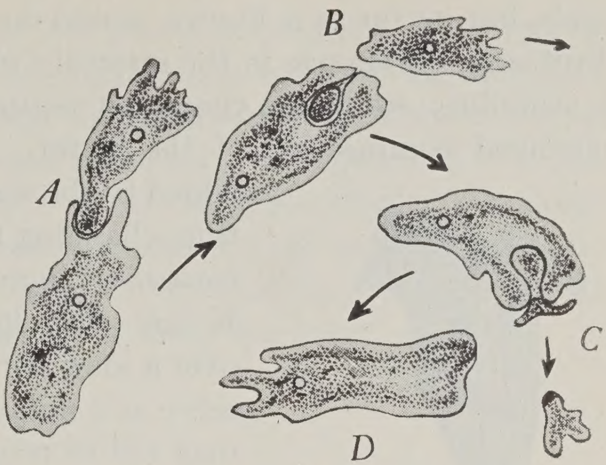


FIG. 237. In *A* the large ameba has begun to engulf a piece of the smaller. In *B* the free part of the small ameba moves away; the pinched-off piece remains inside. In *C* and *D* the pinched-off piece escapes.

A stimulus is any change in the environment (surroundings) which can bring about a response in an organism. All Protozoa are sensitive to a variety of stimuli and they respond to these stimuli in a variety of ways. A simple, direct response to a stimulus is spoken of by some scientists as a *reflex act.* If you have ever watched living Protozoa you have seen some of their common reflexes. When a paramecium in the course of its swimming meets some solid object it reverses its direction. However, when it meets some smaller organism which can serve as food, it does not reverse its cilia. Therefore, when the cilia lining the gullet sweep a strong current of water inward the smaller organism is carried along with it. The paramecium is exhibiting reflex acts typical of a protozoan.

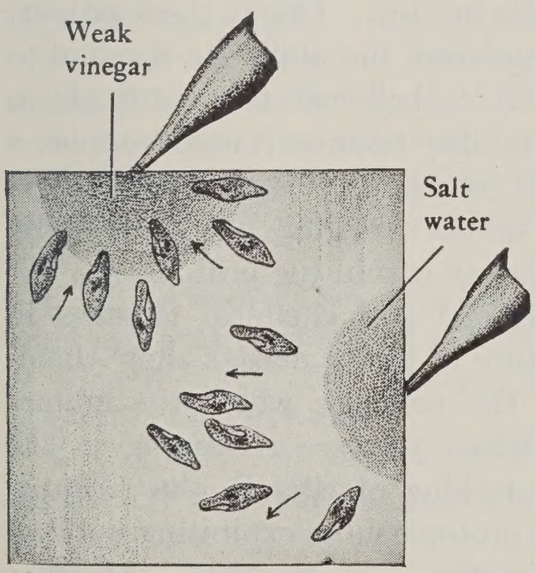


FIG. 238. By means of a medicine dropper salt water and weak vinegar are run under the cover glass. How do paramecia respond to each of these stimuli?

To what kinds of stimuli do Protozoa respond? There are many possible changes in the environment which serve as stimuli to living things. When a solid object comes into the path of the protozoan its environment is changed; this is a mechanical stimulus. Sound waves are also a mechanical stimulus to many animals, but, as far as is known, sound does not serve as a stimulus to Protozoa. A change in the intensity of light or in its color acts as a stimulus; so does a change of temperature, or a change in the chemical composition of the water. Food or other substances added to the water change its composition, thus changing the environment of the protozoan. There are also electrical stimuli. If any stimulus is applied continuously, over a long period of time, it may cease to serve as a stimulus, and in time the animal may fail to respond. This should not surprise you, since you know that a stimulus is a *change* in surrounding conditions. *Exercises 1, 2, 3, 4.*

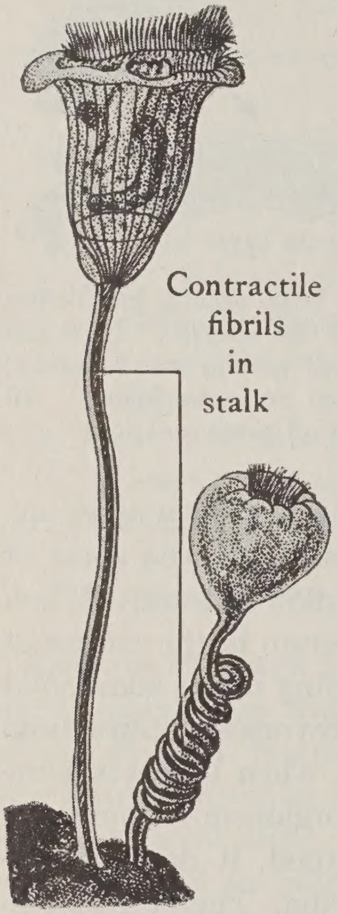


FIG. 239. Vorticella, a tiny one-celled animal, is attached by a contractile stalk. One Vorticella has just been touched by a glass rod. How did it respond?

What enables Protozoa to respond to stimuli? Protozoa consist of protoplasm, and protoplasm, you have learned, has several properties which make it different from lifeless matter. One of these properties is *irritability,* the ability to respond to stimuli. It is believed that protoplasm shows irritability because it is so complex a substance physically and chemically. Changes in the environment may easily cause a change within the protoplasm.

The physical and chemical changes in the structure of living matter show themselves in the response which the animal makes. When you see streaming in the ameba or lashing of cilia in the paramecium, the protoplasm is exhibiting another of its properties — *contractility.* At other times, protoplasm may be changed in such a way as to secrete various chemical compounds. Its response then is one of secretion.

It is only protoplasm that has these properties, so that you can say that Protozoa are sensitive to stimuli and respond to them because they are made of highly complex living matter.

Why is it that Protozoa seem to behave in an "intelligent" manner? As you watch a protozoan backing away from an object or sweeping food into its gullet you get the impression that it knows just what it is about. But the protozoan is not thinking and does not know what it is doing, even though its reflex acts are useful to it. You may ask why Protozoa make correct responses if it is not intelligence that directs them. It is because organisms making responses unfavorable to themselves quickly die and leave no offspring. Thus all Protozoa capable of continued existence will always seem to show intelligence in their behavior.

Exercises

1. (*a*) How do paramecia respond to various chemicals? You should have a rich paramecium culture for all these experiments. See directions earlier in the book. Find a paramecium which has come to rest near some food particles. Run a drop of dilute iodine solution slowly under the cover glass. Observe the surface of the animal closely. What do you see? How do these structures differ from the cilia? Under natural conditions the trichocysts are used for protection. What is the stimulus? What is the response? Is the behavior you have just seen useful or harmful to the organism?

(*b*) Now run a drop of blue fountain-pen ink under the cover of a second slide. What do you observe?

2. Try a little red ink on a third slide prepared as above. Do all foreign chemicals seem to produce the same response? What objections might be raised to drawing conclusions from what you observe? Explain fully.

3. If you have a microprojector, project some paramecia on the screen and run a weak electric current through the water. What is the response of paramecia? If other Protozoa are available find out whether they respond in the same way.

4. Can you devise an experiment to show the response of Protozoa to light? Try it and record your observations. Discuss the experiment with the class.

Problems for Classroom Discussion

1. Explain why paramecia which back away from a tiny sliver of wood do not back away from a small particle of food.

2. Can you name any responses of a protozoan that are not helpful to it? Is each, generally speaking, useless or harmful?

3. The darting out of trichocysts is a protective device. Can you explain why paramecia make this response when ink is put on the slide?

4. If you create a current in the water of a culture jar and the paramecia are pulled along by the current is this movement a reflex act? Why or why not?

5. *Summary.* Stimulus, response, irritability, and reflex need to be explained. When you can do that you are ready to summarize briefly.

Activities for the Junior Biologist

1. Can you devise an experiment to find the effect of a change of temperature on Protozoa? If you have a good culture of amebae, try it.

2. If you have seen the response of a protozoan to light it would be interesting to discover whether certain rays call forth more of a response than others. You may use prisms or photographic filters to obtain the light rays you wish to test.

3. Do paramecia respond to gravity? Plan an experiment to find out. (*Hint.* Use a test tube.) Can you devise a control? Discuss this with your classmates.

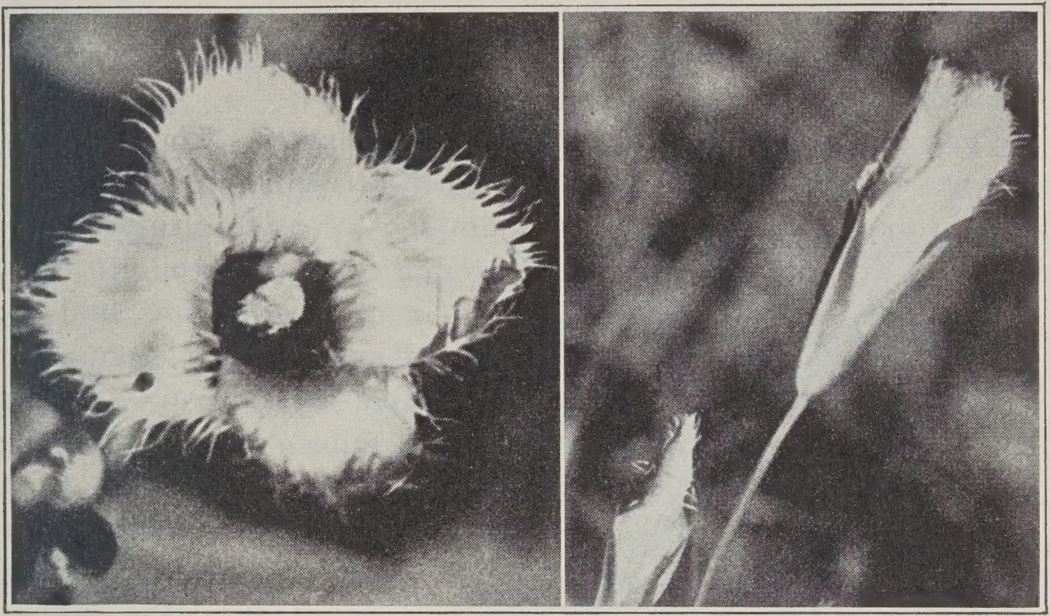
4. What would paramecia do if two stimuli with opposite effects were applied at the same time? Light and gravity might be tested. Present your results to the class.

5. Using a U-tube and one or two dry cells, devise an experiment to test the response of Paramecium to an electric current. What is your control? Explain.

Problem 2. How Does the Behavior of Complex Plants Compare with That of Protozoa?

What responses to stimuli are shown by some complex plants? When leaves flutter in the breeze or cornstalks bend under the force of the wind the plant is not responding in the way in which the ameba does when it pulls in its pseudopods with a rise in the surrounding temperature. In such a case the plant is moved by outside forces just as is the kite which, caught by the wind, soars up into the sky. But plants, like Protozoa, do make simple responses to stimuli. Their protoplasm shows irritability and they perform reflex acts. When, for example, an insect touches the sensitive hairs on the leaf of Venus's-flytrap, the leaf, which is hinged down the middle, doubles up on its hinges and traps its prey. *Exercise 1.*

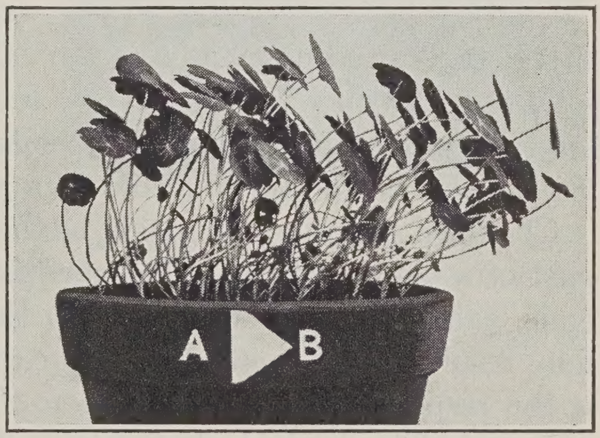
What responses are shown by the more common plants? Such a marked response as you have just read about is the exception among plants. The usual responses common to the more complex



Photos by Frank Gehr

FIG. 240. Fringed gentians in the daytime and at night. What might be the stimulus that causes this response?

plants are less easily observed because they are extremely slow. Yet some of them may be familiar to you. If you leave plants like the geranium, ivy, or begonia undisturbed on a window sill for some days, the stems and leafstalks will turn toward the source of light. There is a slow response to a stimulus. But in this case the response is not only slow but is of a peculiar kind. It is a direct turning toward the *source* of the light in such a way that all parts of the face of the leaf receive equal illumination. When a reflex is of this kind — a turning toward or away from the source of a stimulus — it is called a *tropism* (troh′pizm). This particular tropism, in which the stimulus is light, is called *phototropism* (fo-tot′ro-pizm — light turning). The stem and leafstalks, since they turn toward the light,

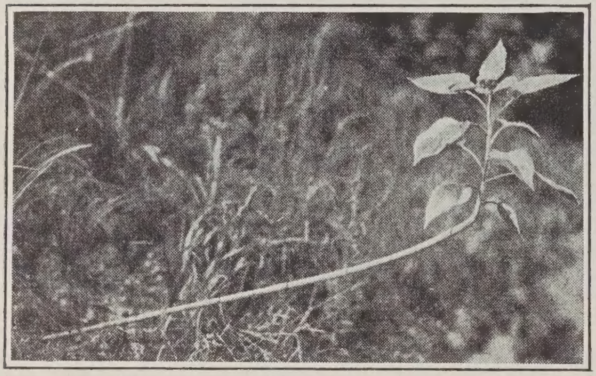


© P. Blakiston's Son & Co., Inc.

FIG. 241. Where was the source of light to which these nasturtium plants responded?

are said to show positive phototropism. The turning of a part away from the light would be known as negative phototropism. *Exercises 2, 3.*

What other stimuli cause tropisms in plants? There is one stimulus to which plants are sensitive and to which most animals fail to respond — gravity. The main root of a plant turns down toward the center of the earth, the stem grows away from it. The root is therefore said to show positive *geotropism* (jee-ot′ro-pizm — earth turning) and the stem, negative geotropism.



H. Schneider and J. Schwartz

FIG. 242. This young sunflower plant had been blown down by the wind. Since that time the tip of the stem has grown. Can you give two possible reasons why it grew up?

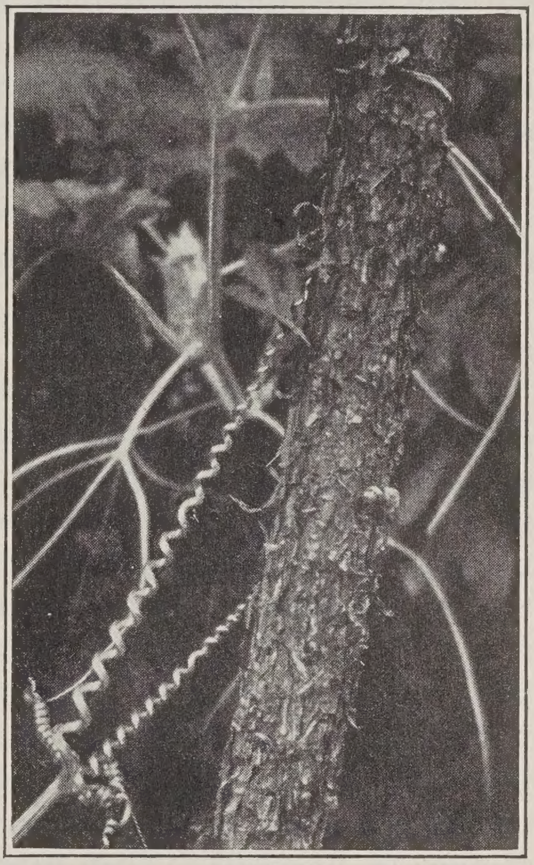
Mechanical stimuli also cause striking tropisms in some plants. The grapevine, the pea plant and others which grow tall and have stems without much wood need a support in order to hold their leaves up to the light. These plants have specially sensitive structures known as *tendrils.* The tendrils grow toward any solid object with which they come in contact, thus winding themselves about a support in tight coils. This is a case of positive *thigmotropism* (the turning toward a solid object).

Chemical substances may act as the stimulus which causes some part of a plant to turn. The unequal distribution of water, minerals, gases, or other substances in the neighborhood of the plant may result in a *chemotropism.* One very common example of this is the response of a root to water. This special kind of chemotropism is known as *hydrotropism.* Some plants may exhibit a *thermotropism* (response to heat). As you can see, plant protoplasm is sensitive to a variety of stimuli. *Exercises 4, 5.*

In what respects do the responses of plants differ from those of Protozoa? The responses of plants are in almost all instances tropisms, movements which turn a part of the plant directly toward or directly away from the source of the stimulus. While Protozoa, too, sometimes turn themselves toward or away from the source of the stimulus, thus showing tropisms, more of their responses are not tropisms.

A more important difference between the response of the plant and that of the animal is that in the protozoan the response occurs immediately after the stimulus is received while in the plant it usually does not show for some time, often not until many hours or days later.

By what methods do plants bring about their responses? The principal reason why plants, as a rule, respond slowly is that they have no cells that are highly contractile; they cannot move themselves and turn as a protozoan does. Instead, the change in position is caused by differences in the rate of growth of cells or by the enlarging of some cells. In some cases the stimulus causes the cells on one side of the stem or root to grow faster than the cells on the other. This unequal growth results in the bending or turning of the stem or root. Naturally such a response is slow and you may not observe the results of the growth for several days after the stimulus has been applied. In other cases the stimulus causes some cells to take in large amounts of water. When the cells on one side of the plant do this the stem or leafstalk bends away from the enlarged cells.



H. Schneider and J. Schwartz

Fig. 243. Can you see the squash tendrils curled around the dead pine stem? The tendril tightens up in a corkscrew after its tip has caught on an object.

Some plants, on the other hand, respond rather rapidly. The insect-eating plant promptly closes on its prey; the sensitive plant (Mimosa) when touched at once allows its leaves to droop. In a case such as this the response is caused by a different mechanism.

Under each leaf and leaflet in the sensitive plant is a little swelling. The cells within this swollen portion are stretched to capacity with cell sap. They are said to be in a state of *turgor* (tur′gore); that is, the cells are *turgid* (tur′jid). Of course, this makes them stiff in the same way that a very full hot water bag is stiff. Because they are firm these turgid cells help to support the leaf. But when stimulated their cell membranes change; the cells lose water and become soft. They lose their turgor. As a result they no longer act as a support and the leaf droops.

Since the stimulus is usually received by one group of cells and the response made by another group, "messages" must go from one to the others. Sometimes they travel along strands of protoplasm connecting cells. Often, distant cells are stimulated by substances that are carried in the ducts.

How does the behavior of complex plants resemble that of Protozoa? Complex plants and Protozoa are different in structure and habits of life. Therefore you would expect to find differences in their behavior. But fundamentally complex plants and Protozoa are alike because they are both made of protoplasm. For that reason, both kinds of organisms are sensitive to stimuli, frequently even to the same kinds of stimuli. Both perform reflex acts, which may be in the nature of tropisms. As in the Protozoa, the responses in plants that you have seen and read about seem for the most part to be for the good of the plant. Such responses are not thought of as intelligent behavior any more than are the responses of Protozoa. They exist in plants because plants that failed to make such responses probably died. Those that gave useful responses survived. By their responses both kinds of organisms put themselves into the most favorable relations with the environment.

Exercises

1. How does the tulip blossom respond to changes in temperature? Place a tulip blossom standing in a glass of water into the ice box. After half an hour or more place it in a warm room. What do you see? In what respects is the method of this experiment faulty? Why can you not draw conclusions from what you have seen? What should you do to make this experiment valid?

2. To demonstrate positive phototropism. Obtain two similar small boxes with sliding or hinged covers. Stand the boxes on end with the door facing you. In one cut a window in the top. In the other cut a window of the same size on one side about halfway up. Place moist sawdust at the bottom of each box. Plant some young pea seedlings in each. Close the cover and permit the boxes to stand in a warm room. Keep seedlings moist. Observe after some days. Record your observations, and explain.

3. How do roots respond to light? Cover a tumbler of water with gauze. Suspend several mustard seedlings with straight roots from one to two inches long on the gauze so that the roots are wholly in water. Place a wooden box with a narrow window along one side over the tumbler. Examine after some days. Describe. Does this experiment need a control? Why or why not? What kind of phototropism is shown by mustard roots?

4. How can you show the positive geotropism of roots and the negative geotropism of stems? Line a jar with heavy, wet blotting paper, making sure that the light is excluded. Cut a sheet of cork so that it can stand up in the jar. Cover the cork with wet blotting paper. Pin pea seedlings to the cork, making sure that the pins go through the cotyledons and that the peas do not touch the cork. Pin the seedlings so that the tiny roots and stems point in several different directions. Cover the jar with a sheet of glass, lined with wet blotting paper. Keep the blotting paper moist by adding water when needed. Examine the seedlings regularly for several days. What happens to the roots? to the stems? Is there a control? Can any other stimuli have affected these plants? How can the results be explained?

5. Can you suggest the method of an experiment to show positive hydrotropism in roots?

Problems for Classroom Discussion

1. If you stepped off a table you would fall toward the center of the earth. Is that an example of positive geotropism? Explain.

2. Have you seen flowers closing up or "going to sleep" at night? Explain. Is it light or the lower temperature that makes them close? How could you find out?

3. Venus's-flytrap and the sundew respond when an insect touches them. You can get the same response by using a straw. What kind of behavior do they show?

4. Why do trees growing along the banks of a brook in the forest lean toward the brook?

5. *Summary.* It is important for you to understand in what respects the behavior of plants resembles that of Protozoa. State them in a sentence or two. Then point out the minor differences. What new terms have you learned in this problem?

Activities for the Junior Biologist

1. Do plants respond to artificial light as they do to sunlight? Perform an experiment to find out.

2. By filtering out some of the rays of light you could find out whether a plant is more sensitive to some rays than to others. It would be interesting to find out whether the plant is more sensitive to the red rays which are used in photosynthesis.

3. Time the speed with which a sensitive plant responds to a stimulus. Use a watch with a second hand. Gently stroke the lower midrib of one leaf and watch closely for the first sign of response in that leaf. How long does it take before some other leaf responds? Measure the distance the message traveled in that time.

4. Professor Jennings has written a fascinating book called *Behavior of the Lower Organisms.* Although parts of it are difficult to understand you will enjoy the descriptions of his observations. Can you name the types of behavior he observed? Look up Professor Mast's book, *Light and the Behavior of Organisms.*

Problem 3. How Does the Structure of Many-celled Animals Enable Them to Receive Stimuli and Respond to Them?

What special structures are needed by many-celled animals to enable them to respond to stimuli? You have learned that Protozoa are constantly relating themselves to their environment; that is, they are responding to stimuli. They must respond to food, to other favorable and unfavorable conditions of their physical environment, and to their ever-present enemies.

Of course, this holds for complex animals as well. Since they are many-celled, they have special structures such as the eyes, ears, and other sense organs for receiving stimuli; these are known as *receptors.* Many-celled animals also have special structures for responding: the *effectors.* These may be muscles or glands. Since the organism is complicated in structure, the stimuli will often be received in some part of the body far removed from the part which needs to respond. This means that there must be some way of bringing these parts into connection with one another speedily. Thus there are special cells for sending messages or *impulses* from the receptors to the effectors; the cells that send messages may be called *transmitters.*

How are cells fitted for transmitting impulses? A message can travel easily through a cell. But passing from one cell to another is more difficult. The best arrangement for transmitting impulses, therefore, is to have cells which are drawn out to an enormous length. In this way there need be only a few cells between a receptor and the effector widely separated from it. These transmitting cells, known as nerve cells or *neurons* (new′rons), are of a very irregular shape. Each cell has a long drawn out, thin projection of cytoplasm which may be anywhere from a fraction of an inch to many inches long. In some cases, in a large animal such as man, the cell projection may extend several feet. Of course you could not see a neuron without a microscope even though its projection of protoplasm reached half the length of a man's body. The projection is too narrow.

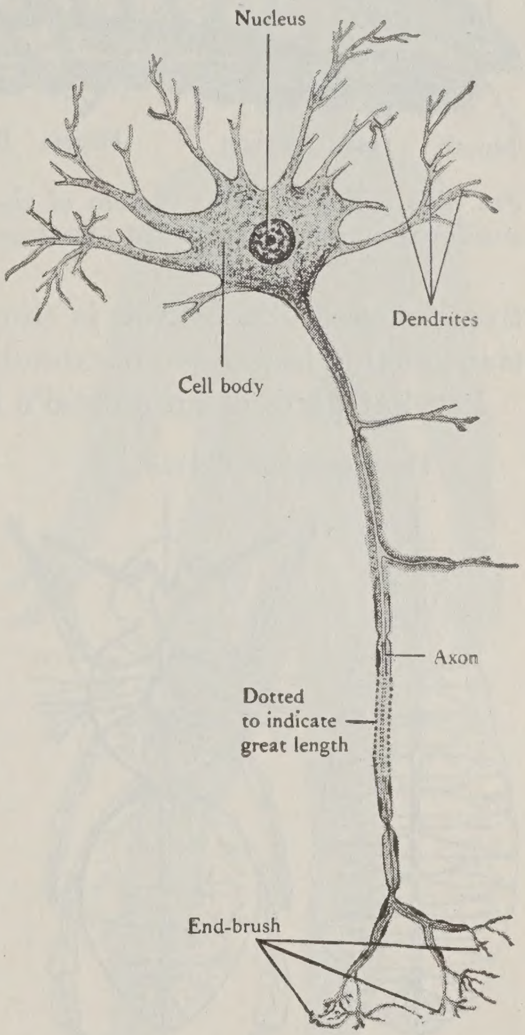


FIG. 244. A neuron is a complex cell. What are its parts? The axon is covered by a sheath which is not part of the neuron.

The axon (see diagram) is like the telephone wire which may be miles long but is extremely thin in proportion to its length. It makes no difference how fine it may be, as long as it remains unbroken the axon can carry messages or impulses. It has been calculated that in man impulses travel along the axon at the rate of about 130 yards a second. It is plain therefore that the receptor can be linked up with the effector almost instantaneously; the response can follow the receiving of a stimulus with the greatest rapidity.

The whole neuron (cell body, axon, and dendrites) is made of protoplasm which possesses the property of irritability to an ex-

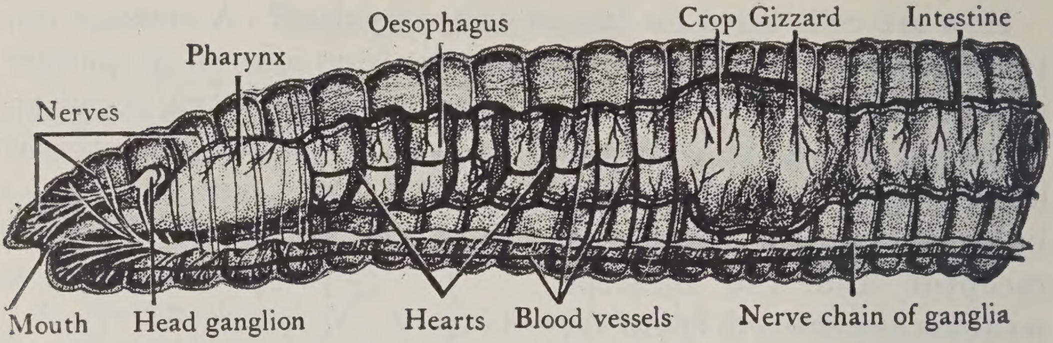

Oesophagus
Crop
Gizzard
Intestine
Pharynx
Nerves
Mouth
Head ganglion
Hearts
Blood vessels
Nerve chain of ganglia

FIG. 245. The nervous system of the earthworm is shown in white. The smaller nerves are too small to be drawn. Where are the ganglia found?

treme degree. A neuron is thus well fitted in two respects for transmitting impulses; it extends far and it is highly irritable.

In what parts of an animal's body do the neurons lie? Since neurons consist of two distinct parts, the cell body with its cluster of dendrites and the very long axon, the paragraph question must be answered in two parts. First, where are the cell bodies? In many invertebrates, such as the earthworm, the crayfish, and the insect, the cell bodies are gathered together in small groups known as *ganglia* (gan′-glee-a). The singular is *ganglion.* Many invertebrates have two strings of ganglia, like strings of beads, along the ventral (lower) side. (See also Fig. 199.)

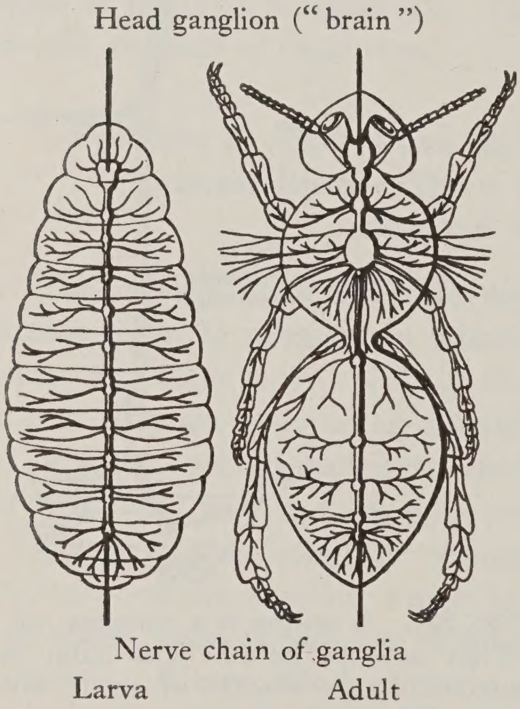

Head ganglion (" brain ")
Nerve chain of ganglia
Larva
Adult

FIG. 246. Chains of ganglia in the honeybee larva and adult. How do they differ? They are found along the ventral side.

In the vertebrates the nerve cell bodies are gathered together in a large mass known as the brain and in the *spinal cord* which is nothing but an extension from the brain. Here the cell bodies are well protected by the skull (or *cranium*) and by the spinal column or backbone. But there are some cell bodies lying in small groups, too; that is, vertebrates also have ganglia. These are found in definite regions in the inside of the body, either near the spinal cord or close to the internal organs. They will not be described in detail here although they are of great importance; if you did not have them you could not remain alive. However, comparatively few of the billions of nerve-cell bodies are in the ganglia. Most of them are in the brain and cord.

Since the cell bodies are huddled together the axons are found running side by side, not lying singly in the body. They are bound together into a sort of cable and protected against injury by a strong covering. The axons in one such cable are so numerous that, thin as each axon is, the bundle of axons is thick enough to be visible to the naked eye. You have seen such bundles of axons in pictures of dissected animals; they are called *nerves*. Because a nerve is a bundle of axons each axon may be spoken of as a *nerve fiber*.

Since each nerve fiber (or axon) grows out of a cell body which lies in the brain or cord, it follows that the bundles of fibers, or nerves, arise from the brain or cord. Of course where it arises the nerve is thick, because it consists of thousands of axons or fibers. But shortly some of the axons part company with the rest and turn off in a different direction. The nerve has branched

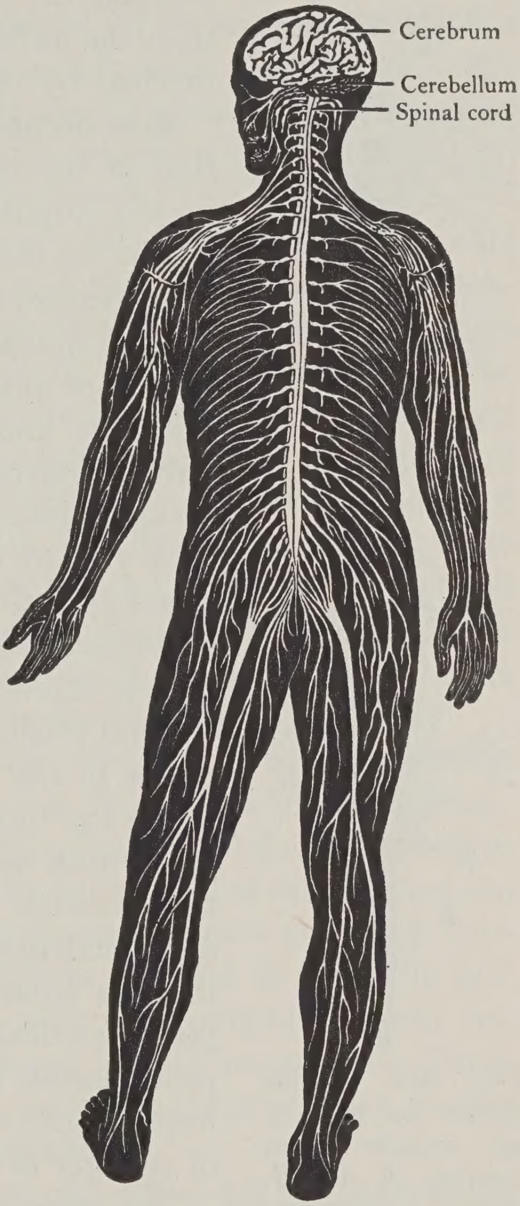


FIG. 247. The central nervous system of man. Only the largest nerves are shown. About how many nerves arise from the spinal cord? Notice how the nerves branch and run to all parts of the body.

and, naturally, each branch is thinner than the original nerve. If you trace these branches you will find that each subdivides again and again. These branches are so numerous that the cells in every part of the body are reached by tiny nerves.

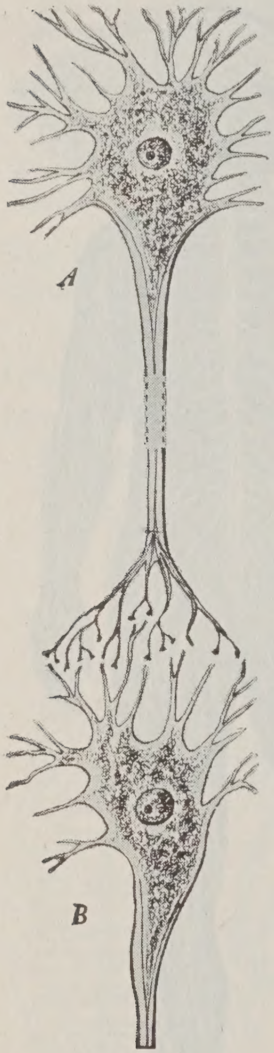


FIG. 248. This shows the path of an impulse from neuron *A* to *B*, across a synapse. Cell *B* is incomplete. Copy this diagram. Complete cell *B* and show how the impulse would get into cell C.

How do neurons do their work? The function of the neuron is the transmission (sending) of impulses. An impulse flows from one end of the neuron to the other. Energy must be developed by the nerve cell because the flow of the impulse is really a flow of energy. The details of this flow are not fully understood but it is known that electrical energy is involved somehow. The electrical currents have actually been measured. But this must not lead you to believe that a nerve impulse is merely an electrical current.

When a nerve impulse starts in a neuron it travels rapidly along the axon until it reaches the end brush. There it starts up similar impulses in the dendrites of other neurons close to the end brush. In this way impulses are relayed from neuron to neuron until they reach the effectors. The region including end brush and dendrites, where the transfer of a nerve impulse from one neuron to the next takes place, is called a *synapse* (sin′aps). There is no protoplasmic bridge at the synapse. That the impulse gets across is certain but the method of transfer is not well understood.

The synapse always offers some resistance to the passage of nerve energy. Although an impulse travels with great speed along the axon, it is delayed at every synapse for a longer or shorter length of time. Sometimes it does not get across the synapse at all.

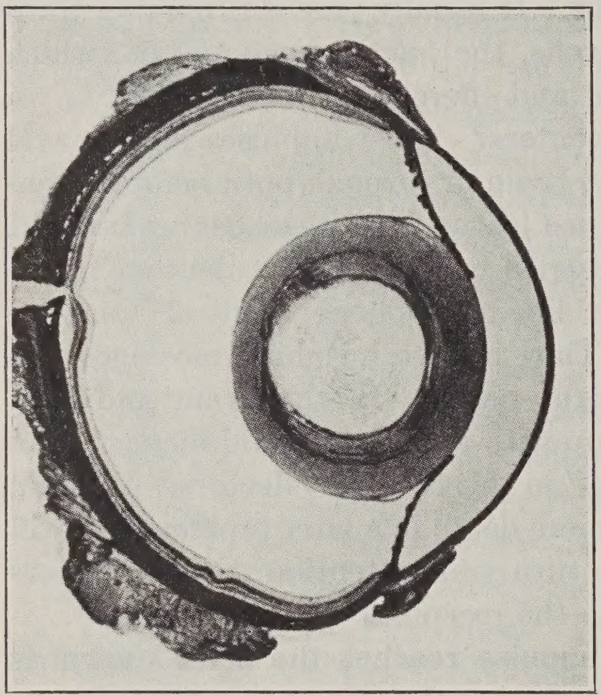
How do neurons differ in the work they do? The impulses that start up when receptors are stimulated flow along axons toward the brain or spinal cord. The axons which carry these are called *afferent* (af′fer-ent — carrying toward) and the complete nerve cells are spoken of as *afferent neurons.* There are other neurons which carry nerve impulses out from the brain or spinal cord to the effectors. These are known as *efferent* (ef′fer-ent — carrying out of) neurons. The nerve impulse rarely goes directly from the afferent neuron to the efferent. It usually passes through a third type of neuron with short axons, the *intermediary* neuron, which serves to connect the afferent and efferent.

What is meant by nerve centers? Most impulses must travel through the spinal cord or the brain or through both before reaching an effector. As you have just learned, the messages are brought in by afferent neurons and carried out by efferent neurons. The cord and brain act, therefore, like a telephone "central" and are spoken of as *nerve centers.* They receive incoming messages and send them out along the right paths. In the brain and cord afferent neurons are hooked up with the efferent and messages are thus sent to the other "party," in this case the effectors. You will study these nerve centers in more detail in a later problem. It will be necessary for you next to turn your attention to the effectors and then more particularly to the receptors.

What happens when the impulse reaches the cells known as effectors? When the impulse reaches the effector something happens in its cells; that is why such cells are called effectors. But what happens depends on which particular kind of cell receives the impulse. If the cell consists of cytoplasm which is highly contractile, it contracts. Such protoplasm is found in a muscle cell. In a complicated animal, muscle cells are common. Many are found near the surface of the body and help in locomotion. There are also internal muscles, in the heart (if there is one), in the alimentary canal, and in other organs.

Often efferent impulses are sent to cells which are not contractile, cells whose cytoplasm has the power of secretion to an extreme degree. When an impulse reaches them they do what they are fitted to do, they secrete. They may secrete saliva or any other digestive juice; they may secrete tears or sweat or adrenin. Such secreting gland cells are of great importance in a many-celled animal. Much of their work is internal and is often less noticeable than the contraction of muscle cells. For this reason you probably do not appreciate how often this type of effector is set into action.

What provision for receiving stimuli is found in the many-celled animals? You learned that in the Protozoa protoplasm is sensitive to such stimuli as light, chemical substances, temperature, and mechanical stimuli. In many parts of the many-celled animal there are single cells or groups of cells containing protoplasm which is unusually irritable or sensitive to one of these stimuli. These cells are the receptors.



Courtesy Ward's Nat. Sci. Establishment

FIG. 249. A photograph of the frog's eye cut through the middle. The front is at the right. How many of the structures mentioned in the text can you find?

In Hydra, there are simple receptors. Around the mouth and on the foot, among the ordinary epithelial cells, are long narrow cells which dwindle down to fine branching threads. Their cytoplasm is more irritable or sensitive than is the cytoplasm of the neighboring cells. They are receptors which at the same time are fitted for transmitting the message to simple muscle cells or, first, to nerve cells which then transmit the impulse still farther. They are different from the receptors in most animals. *Exercise 1.*

The earthworm, a more complex invertebrate, has receptors for light and several other kinds of stimuli. These sense organs are found in large numbers in the outer covering, particularly at the anterior and posterior ends of the body. Fibers run from these sense cells to the chain of ganglia.

Among the higher invertebrates, such as the insects, and particularly among vertebrates, receptors are far more complicated. Furthermore, in all animals which possess a brain, even a simple one, receptors are connected with special neurons in the brain. In these cases receptors become much more than cells for receiving stimuli. They become organs for gathering information, for the brain is able to understand what the receptors pick up. While the eye receives the stimulus of light the brain "sees." While the ear receives the stimulus of sound the brain "hears." This is true of all the special receptors or sense organs possessed by a complex animal. *Exercises 2, 3, 4, 5, 6, 7, 8.*

What sense organs has man? Man has a large number of sense organs. Besides the eyes and ears he has taste buds, special nerve endings in the nose, and tiny structures all over the skin for receiving stimuli of pressure, cold, warmth, and pain. There are also different kinds of sense organs all over the inside of the body.

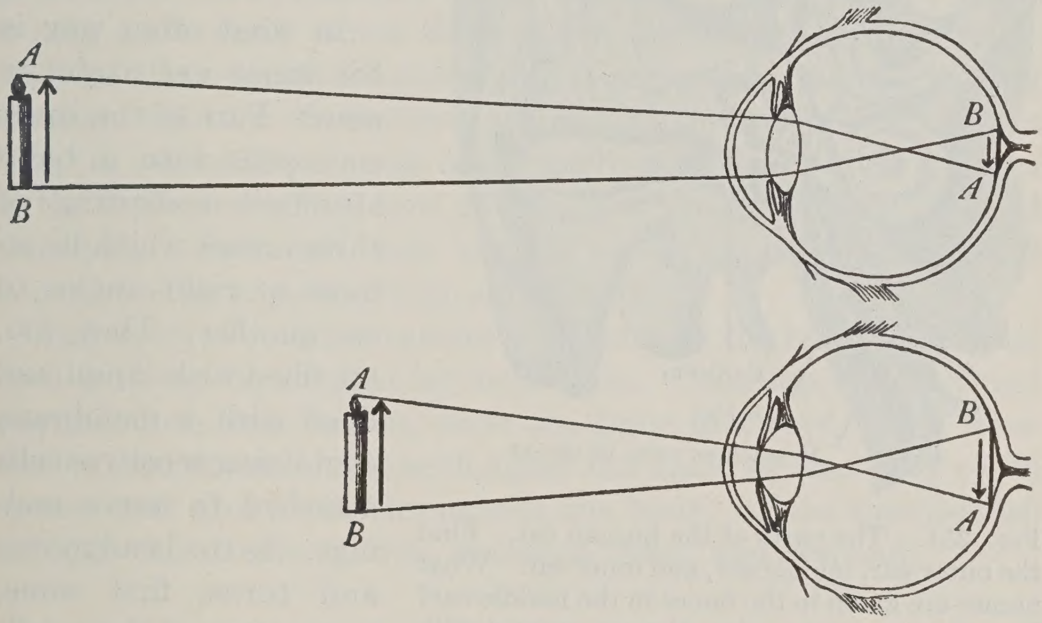


FIG. 250. What change takes place in the lens of the eye when an object is moved closer? Note that the image thrown on the retina is inverted.

The eye is a very complicated organ which has highly sensitive cells for receiving stimuli. These cells lie in the *retina* (ret′in-a), the layer which lines the back of the eyeball. The stimuli picked up by the retina are sent to the brain by the optic nerve. The light rays enter the eye through an opening known as the *pupil.* Then they strike the *lens* which directs them to the retina. The colored part of the eye (*iris*) regulates the size of the opening which admits the light. All these parts are protected from injury by the tough *cornea* (kor′nee-a — the white of the eye).

In the ear, the sound waves are caught by sensitive cells lining a snail-shell-like bone (called the *cochlea* — kok′lee-a). This snail shell, which is about one inch across, is sunk deep down in the head. It makes up the inner ear. It is filled with a liquid. When sound waves hit the drum at the entrance to the middle ear, the vibrations are passed along the tiny bones known as the *hammer*, *anvil*, and *stirrup* which stretch across the middle ear. Then the vibrations reach the tiny membrane at the entrance to the snail shell. Thus waves are set up in the liquid which fills the snail shell, and the sensitive cells in the inner ear receive their stimuli. *Exercises 9, 10.*

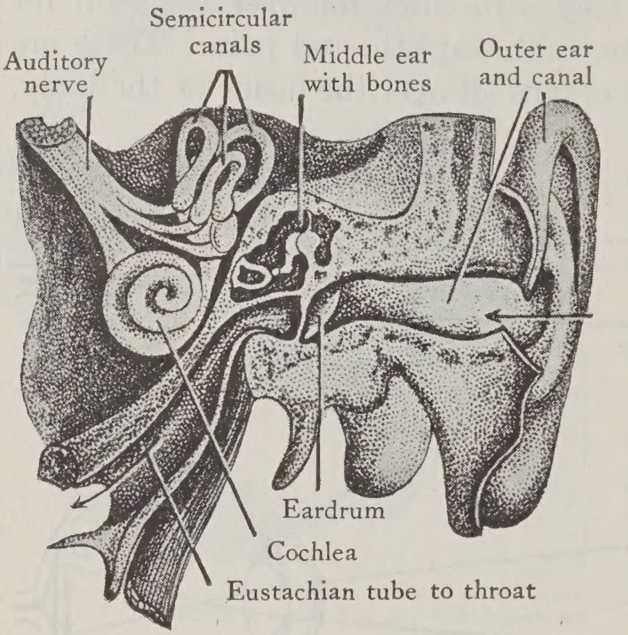


Fig. 251. The parts of the human ear. Find the outer ear, middle ear, and inner ear. What names are given to the bones in the middle ear? By what passageway does the ear connect with the throat?

In what other way is the inner ear useful to man? Part of the inner ear opens into a bony structure consisting of three arches which lie almost at right angles to one another. They, too, are filled with liquid and lined with a membrane containing sensitive cells attached to nerve endings. As the head moves and turns, first some, then others of these cells are stimulated by the liquid. Thus man's brain is kept informed of the position of these arches (*semicircular canals*) so that it is possible for a human being to know whether he is standing on his head or on his feet. The function of these arches is to help man to retain his balance.

How are many-celled animals fitted to receive stimuli and respond to them? Since many-celled animals have different organs and structures for performing their various functions it is natural that they should have special structures for performing reflex acts. They have parts for receiving stimuli and parts for responding. And since these two may be far apart they have structures for connecting them. That is, they have receptors, effectors, and transmitters. The receptors, in the less complex animals, are merely groups of sensitive cells, sensitive to one kind of stimulus only. But in higher animals many receptors are complicated; and, besides, they are connected with neurons in what is called the "brain." It is known that the brain is a necessary part of this combination because it has been shown that if certain brain cells are destroyed the animal can no longer see. Likewise if other brain cells are destroyed the animal can no longer hear, smell, or taste, and so on.

Because the body of higher animals is so large and complicated the speedy linking up of receptor with effector becomes a matter of great importance. For this the neuron is well fitted because it has a long axon along which the impulse can travel without interference. But equally important in a complex animal is the making of many different connections. This is made possible by the fact that the cell bodies of most of the neurons are found close together in the brain and spinal cord and in some special ganglia situated internally. Each cell body too has branching dendrites so that it can receive impulses from many cells.

And every effector, no matter how far from the brain and spinal cord it is, can be reached by some axon. Countless axons, bound together into large nerves, leave the brain and cord. But these nerves soon divide and branch again and again so that they reach muscle and gland cells throughout the body. Thus many-celled animals can receive stimuli, transmit them, and respond.

Exercises

1. What response does Hydra give to a sudden bright light? Search in the aquarium for a Hydra with its body extended. Flash a strong light on it. Is it sensitive to the light? How do you know? Has it eyes?

2. What is the structure of the eye of some common insect? With a hand lens, examine the head of a grasshopper, of a fly, of a bee, or of any other common insect. Note the position of the large compound eyes. Describe the surface of the eye. In how many directions can the insect see? Are the eyes movable? Are there eyelids? Note the number and position of the simple eyes, if any are present. If you can rig up a bright light at the end of a cord try to find out whether an insect sees. Use a moving object. If you get responses, will that show that the insect sees with its eyes? Why or why not?

3. Are there separate receptors for "hot" and "cold" in man? Mark out a one-inch square on the forearm of a blindfolded student. Slightly heat a needle; cool another in ice water. Using the blunt end, touch nearby points within the marked area with the hot and cold needles. Put a dot on a sheet of paper to correspond to the points at which warmth is felt and a cross to indicate where the needle felt cold. Do the dots and crosses fall on the same spots? Repeat this experiment, using other students. Are the receptor maps exactly alike?

4. In what parts of the tongue are the taste buds sensitive to substances that are sour, bitter, sweet, or salt? Blindfold a student. Test various parts of his tongue with sugar, salt, quinine, and lemon juice. Let him rinse his mouth after each test. Record your results. Repeat with several other students. Draw a diagram of the tongue and indicate the sensitivity of each part to the four substances.

5. How could you show that you smell rather than taste most substances?

6. Do foods have the same flavor if you are blindfolded?

7. What is one use of saliva besides those already learned? Wipe your tongue dry and lay some grains of sugar where you should be able to taste them. How long does it take before you are aware of sweetness? Why? Name all the functions of saliva.

8. Are touch receptors evenly distributed over the body? Blindfold a student. Your results will be better if he does not know what you are going to do. Keep accurate records. Touch his forearm lightly with the points of two dissecting needles or other fine-pointed instruments, the points being about $\frac{3}{8}''$ apart. Does he feel two points or one point? Moving the points of the needle closer together or farther apart, test various parts of the hand and forearm. For several places find the greatest distance at which he thinks the two needles are one. What was the shortest distance between the points at which he could feel both? What would this indicate? Now repeat the operations on the palm, fingers, back of the hand, cheek, forehead, and so on. Where are touch receptors closest together? Repeat the entire experiment using different subjects. Why is this necessary? What are your conclusions?

9. How do near-sighted and far-sighted persons see? Copy the upper diagram which shows how the light rays from a candle are thrown on the retina. Leaving the image where it is, erase the back of the eyeball and draw a long eyeball instead of a spherical one. Where does the image fall with relation to the retina? A near-sighted person has eyeballs like this. Why does he not see objects clearly when held at the normal distance from the eye? A far-sighted person has eyeballs that are too short so that the image falls back of the retina. Draw this condition.

10. What advice would you give if an insect crawled into the outer ear? What would stop its passage? If it should be a stinging insect what treatment would be most likely to make it use its sting? Some insects are positively phototropic; what might you try?

Problems for Classroom Discussion

1. Why may the reaction to a stimulus received by a single sense organ involve a large part of the body in a very short time?

2. What would happen to a part of the body if the efferent neurons in it were destroyed? What would happen if the afferent neurons were destroyed? If both?

3. When an earthworm has its smell receptors stimulated, which effectors may respond? By what route is the impulse sent from the receptor to the effector?

4. What would be the result of destroying the part of the brain in which the nerves from the eyes end?

5. The image that falls on the retina, like the image that falls on the film of a camera, is upside down. Yet you see things right side up. How can you explain this?

6. What may be wrong with the eyes of a person who squints?

7. Examine the diagram of the ear. Why does ear trouble often follow a sore throat or a cold in the head?

8. Why may a blow on the ear cause serious injury? Why does diving sometimes cause injury?

9. Why may people suffering from an ear disease feel dizzy?

10. *Summary.* Look back to the problem question. Give an answer that would hold for animals in general. Look through the problem and pick out the paragraphs or sentences which you consider particularly important. It would be interesting to compare your list with those of your classmates to see whether you can reach an agreement.

Activities for the Junior Biologist

1. Prepare a simple model to show afferent, efferent, and transmitting neurons. Use strings of different colors.

2. Cover up the simple eyes of an insect with black adhesive plaster. Then cover each compound eye separately; then both together. Do you note any differences in the responses when you apply a light stimulus?

3. Is the earthworm equally sensitive to light at both ends? What experiment would you use to determine this?

4. Devise an experiment to find out how an earthworm responds to the vibration of a nearby blow.

5. Is an earthworm sensitive to smell? Put a splint that has been dipped in xylol near it. Find out if all parts of the body are equally sensitive to smell.

6. Do any insects perceive color? Look up and report on color perception in bees.

7. Look up methods of detecting color blindness in human beings. If you can get the proper materials, ask your teacher to try some of these tests in class.

Problem 4. What Kinds of Behavior Are Found in the Many-celled Animals?

How do complex animals respond to sudden stimuli? The sound of an automobile horn close to the ear, a sudden flash of light, the striking of the snake behind the glass of its cage, the accidental touching of a very hot object call forth the same response in you as in me. All of us start; that is, we draw away because certain muscles contract. The stimulus is received by its appropriate receptor and a nerve impulse is transmitted at the rate of about 400 feet per second to the nerve cell body. In some of the examples mentioned above the cell body of this afferent neuron lies in the brain; in some, it lies directly outside the cord. These afferent neurons at once pass the impulse on to others, the intermediary neurons, which in turn stimulate the efferent neurons. Thus messages are speeded to the effectors; that is, muscle or gland cells.

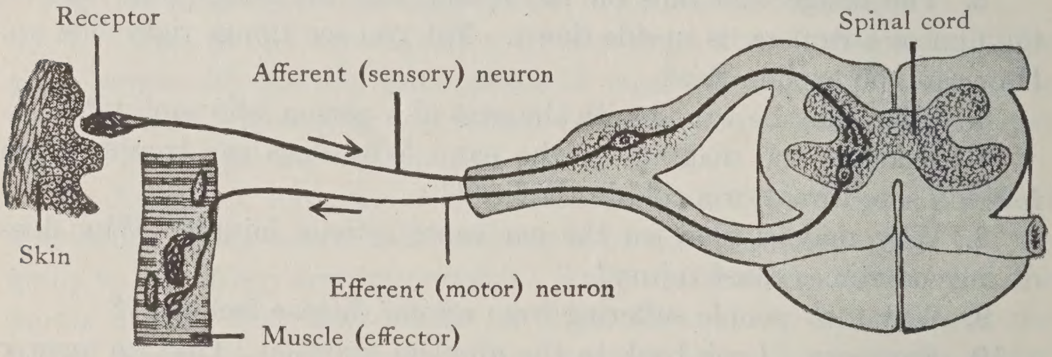


FIG. 252. The simplest type of reflex arc. No intermediary neuron is shown. Note that the afferent neuron is different from the neurons you have seen pictures of before. It has two axons. Where does its cell body lie?

It takes a long time to trace the course of the impulse but you know how quickly the response follows the stimulus. This is a reflex act in a many-celled animal. It is like the reflex in Paramecium, only the many-celled organism has separate receptors, transmitters, and effectors. Each such chain of receptor, afferent neuron, intermediary neuron, efferent neuron, and effector is called a *reflex arc*.

All the parts of the reflex arc are present when the child is born or they form soon after birth. Messages travel along this arc naturally, without practice. That is, the reflex response need not be learned by man any more than backing away from a solid object need be learned by Paramecium. This idea is sometimes expressed by saying that the child is born with a pattern for such behavior laid down in its neurons. An animal that was born without nerve connections for a protective reflex arc of this kind would be quickly killed off in the struggle for existence. It would leave no offspring of its own kind. Only animals that have such connections survive.

How may you become conscious of a reflex act? You have read that the only nerve cells which can give you consciousness of stimuli received through sense organs are nerve cells lying in certain regions of the brain. When you accidentally touch a hot stove and pull your hand away you know that you have touched something hot. The diagram showed that the impulse was sent to the cord and out to the muscle. An afferent impulse must, in some way, also reach the brain. To illustrate its path you would have to add another cell body to your diagram; it lies in the spinal cord close to the synapse shown. The axon from this cell body runs up to the brain. When the impulse passes from the afferent to the efferent neuron in the cord it passes to this other neuron too; by the time the muscle is stimulated the brain cells have become conscious of the heat. But you can see that the brain cells do not direct the pulling away of your arm. That the brain cells do not direct the response can be shown by experiment with a frog. The frog can be etherized and the brain completely cut off from the cord. When the side is irritated with acid, the foot is brushed against the body in just the same way as it would be in a normal frog. Evidently, the brain is not needed for the reflex act. *Exercises 1, 2, 3.*

What other common reflexes do complex animals show? Reflexes are not always of the violent kind described above. When a cinder flies into the eye, the tear gland secretes more actively and the eyelid blinks. An impulse travels along the afferent neuron, is passed on to efferent neurons, and ends in muscle and gland cells.

This is a reflex because a reflex arc was established in the body long before the child had learned anything or did any thinking. The baby does not have to be taught to respond to a cinder in the eye.

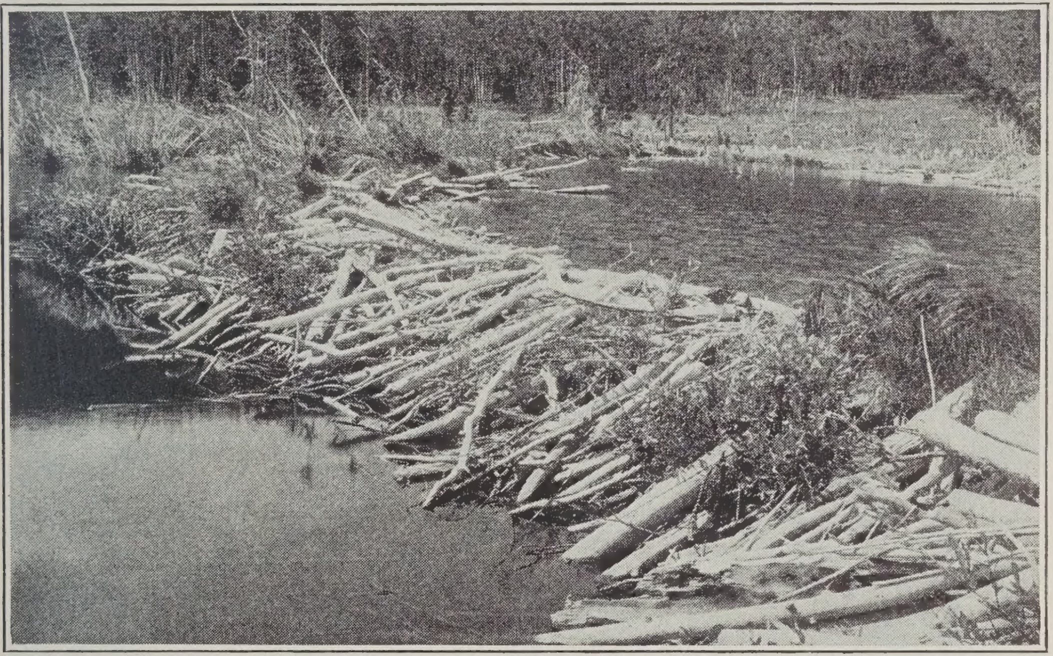
Then there are also many reflexes which are quite unnoticeable because they occur internally. When a ball of food reaches the top of the food pipe, the ring of muscle contracts; by contraction and relaxation of rings of muscle the food is pushed to the stomach. Each muscle movement is a true reflex. When the food reaches the stomach another reflex is started. This time the efferent impulse ends in an effector which is a gland cell; that is, gastric juice is secreted. *Exercise 4.*

What is meant by instinctive behavior? The spider spins its web in a most elaborate design; if you have ever read a description of how it is done you will know how intricate the process is. But if you are obliged to struggle over a statement of the intricacies how could the spider learn to do it? The answer is that the spider never learned. The biologist is sure of this because if he separates a young spider which has never seen a web from others of its kind it will in time spin a web identical with the one spun by its parents. If it is raised with spiders of another species which use a different design it does not imitate what goes on around it but spins its own kind.

Web spinning is obviously more than a simple reflex. It seems to be the product of a reflex act followed by a second reflex of a slightly different kind and a third and so on until the web is completed. When the first thread has been spun it serves as a new stimulus and the second step is performed. This provides a different stimulus and the third reflex is set off. Have you ever laid a string of firecrackers in a row and touched a match to the end one? As it explodes it sets off the next and so on down the line. Well, the spider's reflexes go off in just as regular an order. When an animal performs such a chain or series of reflexes the biologist says it displays *instinctive behavior.* Each act of the instinctive behavior is an inborn, unlearned response. The animal's behavior follows a pattern laid down at birth.

How much of the behavior of most animals is instinctive? The elaborate routine performed by ants in their nests and by bees in their hives occurs because one reflex sets off another. In fact, the behavior of insects and of all other invertebrates seems to be largely, if not entirely, instinctive. Among fish, frogs, reptiles, birds, and even among mammals instinctive behavior may be found.

Experiments have been performed to show that there is no intelligent thought behind all such instinctive animal behavior. Once you upset the routine or break the chain of reflexes you will find the animal behaving in a foolish way.



Courtesy National Park Service

Fig. 253. Well constructed dams like this one can be built by beavers that have never seen a dam. Explain.

Wells, Huxley, and Wells tell of the bush turkey which hatches from an egg laid at the bottom of a heap of decaying plant material. After breaking through the shell, the young bird wriggles up and out at the top of the heap. Then it shakes itself and runs off to find protection. It seems to be showing great intelligence in all its movements; it is doing just the correct thing. But catch the young bird and again place it at the bottom of the pile from which it just wriggled out. It will stay there without a struggle. It was born with a pattern in its nerve cells for wriggling upward as it left its shell, and it did that. But there was no pattern for doing this a second time, after the original stimulus was lacking. When it was called upon to wriggle out again the baby bush turkey failed to do so. What seems at first glance, without experimentation, to be intelligent behavior turns out to be a reflex or a chain of reflexes.

It is probably difficult for you to appreciate how much of an animal's seemingly intelligent behavior is instinctive. Its reflex responses, under normal conditions, are always the "correct" responses, so you may have believed that there must be intelligence

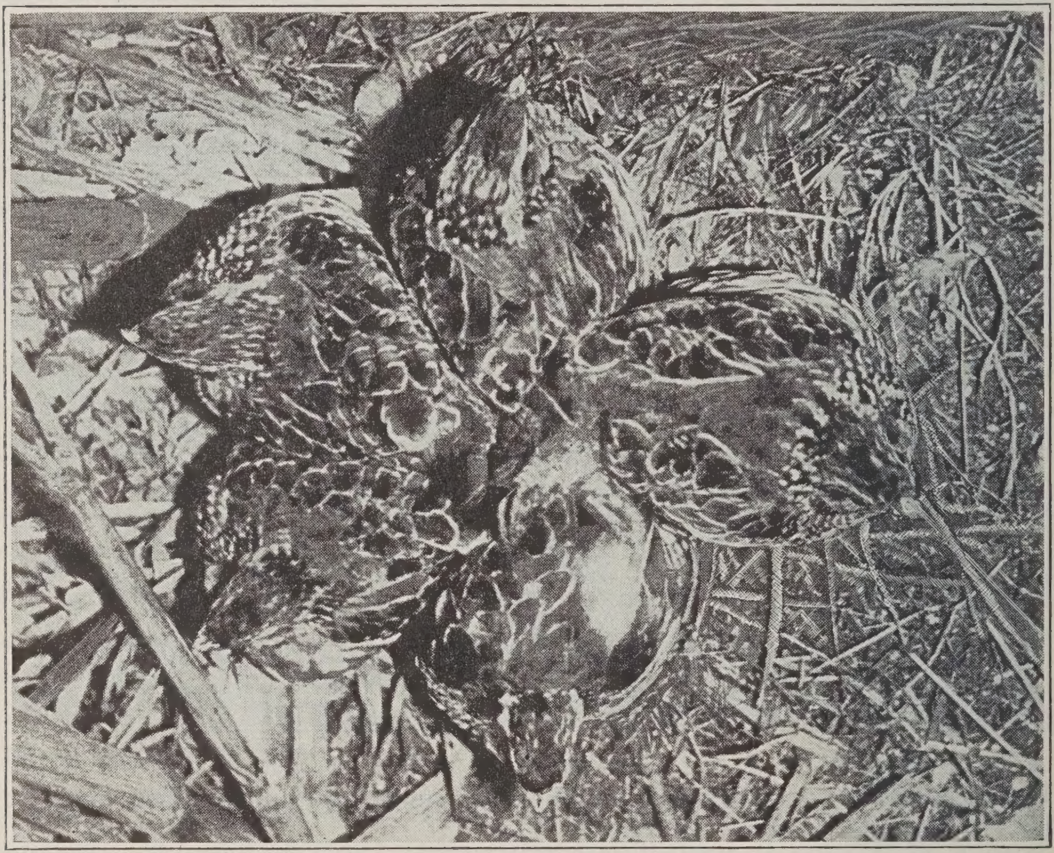


Photo by Frank Gehr

FIG. 254. Young quail in a nest on the ground, photographed from above. Where is the head of each bird? What advantage is there in this position?

back of them. But experiment shows that the responses of animals other than man are largely instinctive.

How may reflexes in higher animals be modified? Reflexes are sometimes changed during the animal's lifetime. You have read how Pavlov succeeded in making the salivary glands of a dog pour out their juices at the sound of a bell! That is, Pavlov was able to substitute for the usual stimuli, sight and smell of food, this new and utterly unrelated stimulus, the ringing of a bell. He accomplished this by ringing a bell every time he fed his dogs.

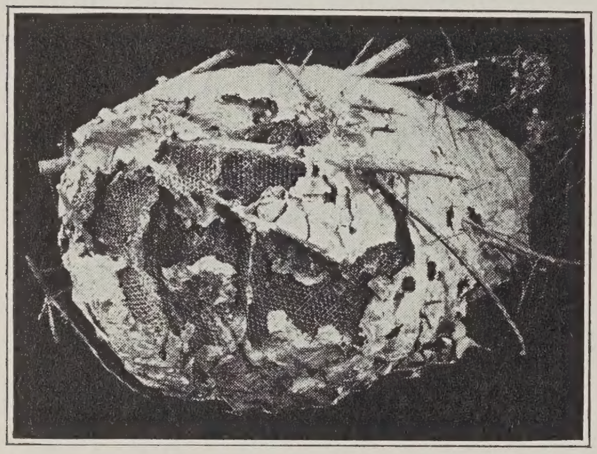
After many repetitions he withheld the meat but rang the bell; the dog's efferent neurons sent an impulse to the salivary glands just the same. Pavlov showed that he was able to substitute a new stimulus for the old and have it attach itself to the original response. The outgoing pathway remained the same but a new afferent pathway was established. Pavlov called the new, changed reflex a *conditioned reflex.*

The conditioned reflex is different from a true reflex; the animal is not born with a pattern for a conditioned reflex. The animal could not conceivably have been born with a pattern for secreting salivary juice in response to the ringing of a bell. A conditioned reflex differs also from the true reflex in this respect: it is not as fixed and regular, for a conditioned reflex can be lost as easily as it is acquired. If the dog fails to receive food when its salivary juices flow in response to the ringing of the bell, the new stimulus soon stops being a stimulus.

What is meant by conditioning? You see about you many examples of the substituting of a new stimulus for the one that is inborn; "conditioning," as it is called, occurs frequently. When you train an animal you use Pavlov's way of conditioning. To teach your dog to respond to your call, you hold out some desired food and call at the same time. The dog comes because he smells the food. But as he smells the food he hears your voice; two stimuli attach themselves to the response made by the dog. The second, unusual stimulus (your voice) is registering every time you repeat your call. Soon you can drop the food stimulus and the call alone will serve to make the dog come to you. In this case the conditioning does not wear off because the dog finds a reward in coming to you even though he gets no meat. Pavlov would have said that the dog had been conditioned. You would say that the dog had learned. Conditioning is one form of learning.

Some animals make the substitution quickly; they learn easily. Sometimes the new stimulus is substituted for the original one so quickly that you do not even realize what is going on. Often, of course, the new stimulus is not applied purposely by man but comes by itself. In either case there is a conditioned act — one form of learning.

What does the scientist mean by the word "learning"? When you hear of learning you may think of memorizing a lesson. This is only one kind of learning and one about which little is understood. But the scientist uses the word in a much broader sense to include all of the large number of activities of an animal's life which are not simple reflex or instinctive acts. Thus you may learn to hold a pencil and move your hand in such a way that you can form letters with ease; you may learn to move your legs and balance your body so that you can skate; you may learn to sing a song. Or you may learn to have digestive juice flow at the sound of a bell. All behavior which is not reflex or instinctive is thought of as learned behavior.

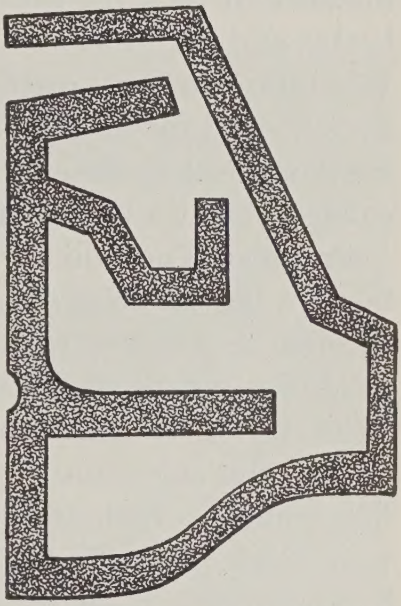


Courtesy Am. Mus. Nat. Hist.

FIG. 255. The building of this wasp's nest depended on a succession of reflex acts. How is it known that the nest building is done by instinct and not by intelligence?

How does the ability to learn affect an animal's behavior? Some animals can learn much, others little or nothing. The more capable an animal is of learning the more unpredictable and varied is its behavior. You know how in the case of the reflex or instinctive behavior of the ant, for example, you can foretell not only what the ants in the anthill in your garden will do under certain conditions, but you know what the ants of the same species in an anthill across the Atlantic Ocean will do under the same circumstances, and you know that they will do it ten years from now. But with learned behavior it is different. An animal capable of learning responds to new stimuli, and it gives responses that may never have been made by it before. It may change its behavior with every important change in its environment. For instance, when pencils, skates, music, and textbooks come into your environment you modify your behavior. How you modify it and to what extent cannot be foreseen. Of course, your parents and other adults try to modify your behavior in the directions which seem desirable to them. But even the teacher, who is trained to produce modifications (learning), cannot control the reaction of so complex an animal as the human being.

What simple kinds of learning do vertebrates show? You have already read how a dog may be conditioned, or may learn, as in Pavlov's experiment. Cases of conditioning, perhaps even among invertebrate animals, may be more common than is generally thought. But vertebrates can learn in still another way as experiments show. Some shade-loving fish were kept in an aquarium which was half in the sun and half in the shade. They tended to gather at the darkened end, especially since this was the end at which they were fed. One day they were gently forced to the sunny end of the tank and kept there by a glass partition placed across the aquarium. This partition contained a small hole just large enough for a fish to pass through. As you would expect, the fish swam back and forth along the glass until, by accident, one struck the opening, when it darted through. That fish had solved its problem purely by accident. The fish was quickly rewarded by getting food and by being in the shade. So far the experiment shows nothing but reflex behavior on the part of the fish, and good luck. But the experiment was repeated many times with this fish and the interesting fact is that after many repetitions the fish got to the hole with fewer and fewer wasted motions and therefore in a shorter time. New nerve pathways were becoming established in the fish; it modified its behavior; it learned, although very, very slowly. The name "trial and error" learning has been given to this type of learning.



Courtesy Professor E. L. Thorndike

FIG. 256. Professor E. L. Thorndike tested chicks in this maze. At first the chicks fluttered about wildly and ran back and forth until they got out. After many trials the chicks learned to find the correct exit with almost no errors.

Many experiments have been performed, particularly with rats and chickens, to test the ability of animals to learn by trial and error. Mazes of various types have been constructed and accurate records have been kept of the animal's attempts to get out and the length of time required for success in each trial. In one experiment the following figures were obtained. What took the rat 28 minutes to accomplish on its first trial, it did in 11 minutes on its second trial, in 12 minutes the third, and 4 minutes the fourth, 5 minutes the fifth and sixth, 2 minutes the eighth, and so on until after about the thirtieth time it ran through its maze to the exit in less than a minute. Between the eighth and thirtieth experiments there were again several slight ups and downs; on the seventeenth day, for instance, it took the rat 3 minutes, but on the whole the rat made better and better scores. The rat was learning by trial and error. It is interesting to note that in such simple trial and error learning as is needed for finding a way through a maze rats were found to learn somewhat faster than college sophomores in an experiment carried out at a university. *Exercises 5, 6.*

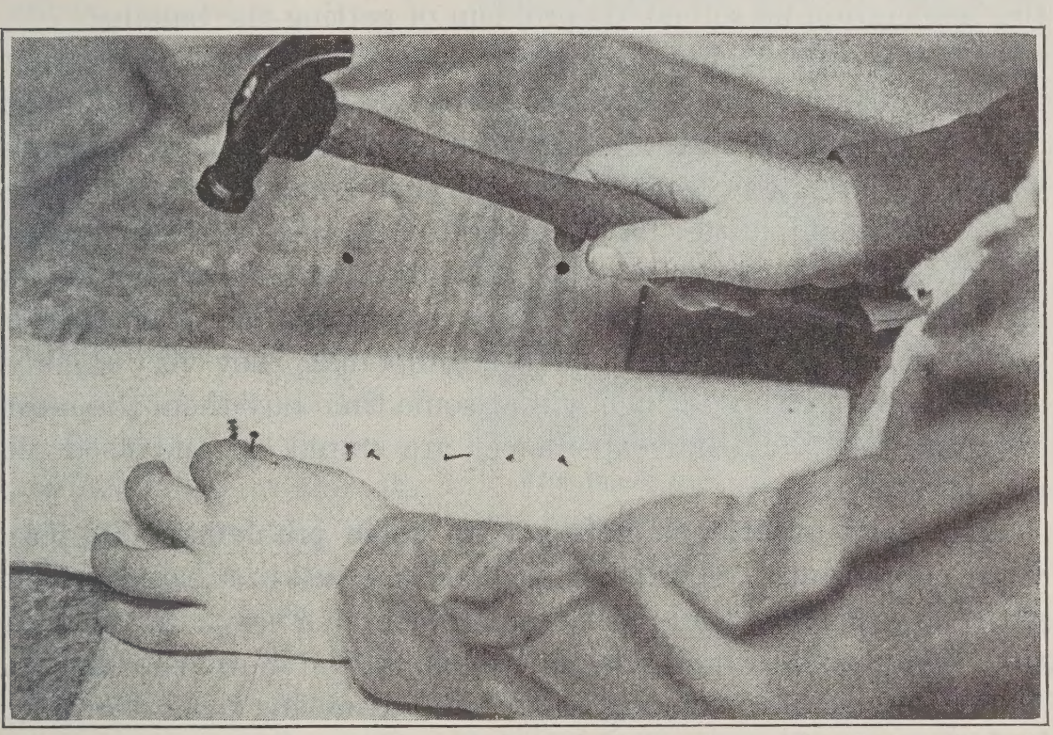
Professor Thorndike tried this: he put a hungry cat in a "puzzle box," a box made of slats too close together for the cat to squeeze through and closed with a door which could be opened from the inside by means of a lever. Food was placed outside the door. After trying to get through the bars the cat moved about and clawed the sides until by accident it pressed on the lever. The first time this took 160 seconds. On successive trials these scores were made: 40, 85, 20, 22, 32, 10, 21, 12, 12, 18, 12, 10, 8, 11, 8, 8 seconds. *Exercises 7, 8.*

What are the necessary conditions for simple animal learning? In all trial and error learning the act must be repeated often. The rat, though it learned more rapidly than the fish, ran through the maze many times before it could be said to have learned.

Yet repetitions are not the only condition necessary for trial and error learning. No matter how frequently the act is repeated, if a reward does not come to the animal as a result of its actions the animal does not learn. The opposite holds true: an animal can learn to avoid something through repeated punishment. An earthworm put into a maze where it has a choice of paths, learns to avoid a certain path if it always gets an electric shock along this course. In the case of the human being the reward, of course, need not be food; it may be the feeling of success or the thrill of accomplishment. Punishment for a human being, too, may be less obvious than an electric shock; it may be merely the feeling of failure or a look of disapproval on the parent's face.

How do some animals use a short cut to solve their problems?

With enough time and perseverance the trial and error method is a good way of learning to do a task and certain animals establish the right response, or learn, after a small number of trials and errors. But some animals seem to have found a short cut to solving their problems, as the following experiment shows. A particularly intelligent chimpanzee was used for the experiment. The ape was given two bamboo rods of different thicknesses so that one could be fitted into the other. A banana was laid outside of the cage at such a distance that it could not be reached even with the use of one of the sticks. The animal began by reaching for the fruit with the longer stick. After several unsuccessful attempts he gave up. Later while playing with the two rods in the back of the cage he accidentally fitted the smaller into the larger. At once he jumped up and reached for the fruit with the jointed stick he had just made. The sticks accidentally fell apart so he again fitted one within the other. This time he secured the banana.



38th Annual Report, Supt. of Schools, New York City

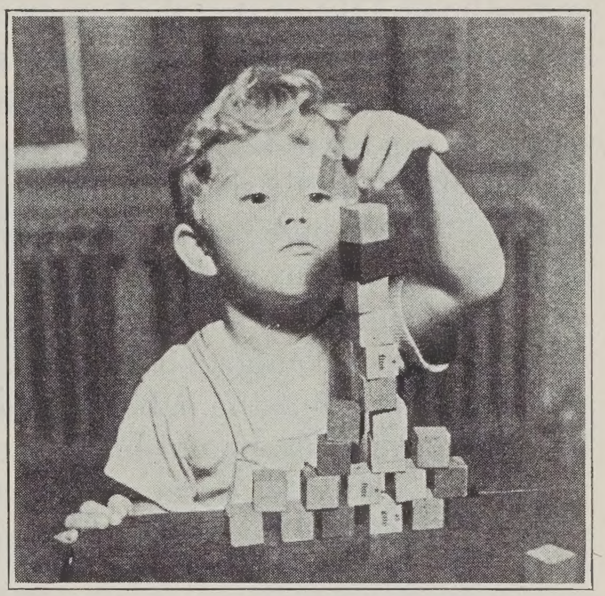
Fig. 257. Humans learn by trial and error. The first trials may have resulted in his hammering his fingers, but with repetition those wasted motions are becoming less frequent.

This experiment shows a very different type of behavior. The ape learned how to secure the banana not gradually through many trials and errors, but suddenly through what may be called reasoning. He did not learn by repeated attempts. But once having fashioned his new tool (accidentally, to be sure), he associated the tool with the banana which he had tried to reach some time before. He immediately recognized the use to which he could put the jointed stick. He had remembered his unsuccessful experiences with the banana and later he connected them with something new, the lengthened stick. Because of his ability to make this association he solved his problem of getting the banana.

In many experiments apes have shown their ability to learn by imitating or by making new associations, a method very different from the simple trial and error learning seen in the experiments with fish, rats, and cats. In experiments carried on at Yale University, chimpanzees have learned to help themselves to food at "chimpomats." They use poker chips of different sizes and colors in place of coins. When poker chips are distributed, even after a meal and while not in sight of the chimpomat, they very eagerly collect and save those which will at some time buy them the most desirable food. Earlier experiences are stored up and used for problem solving.

How does experience help you to solve problems? Suppose you were put into a puzzle box such as was used in the experiment with the cat. You would solve the problem in a very much shorter time because you would not go through all the motions of trying. You would begin by looking about you. Knowing the size of your body from experience and seeing the space between the slats of the box you would know you could not squeeze through. You would not need to try it. In the meantime you would be receiving many stimuli. On one side of the box you would see something that you recognized as a "door." You have seen doors before and you have stored up memories of doors. But you see a lever on the door. You have had experiences with levers before and you remember them. You would try the lever and free yourself. You might have to try the lever several times before it worked (trial and error), but you would free yourself quickly.

You can sit quietly while you make these various observations and connect one thing with another. If you consider with what speed impulses travel and how quickly nerve connections can be made you will realize that in a very short time, without trial and error, you can solve your problem and release yourself. It is obvious that the more experiences you have had and the better you can store up these experiences the more readily you can solve, by reasoning, any problem presented to you. That is where you have a great advantage over the cat. By the time you are grown you have so many stored experiences that much of your behavior is dependent on reasoning.



38th Annual Report, Supt. of Schools, N. Y. City

FIG. 258. What reasoning has gone into this simple activity?

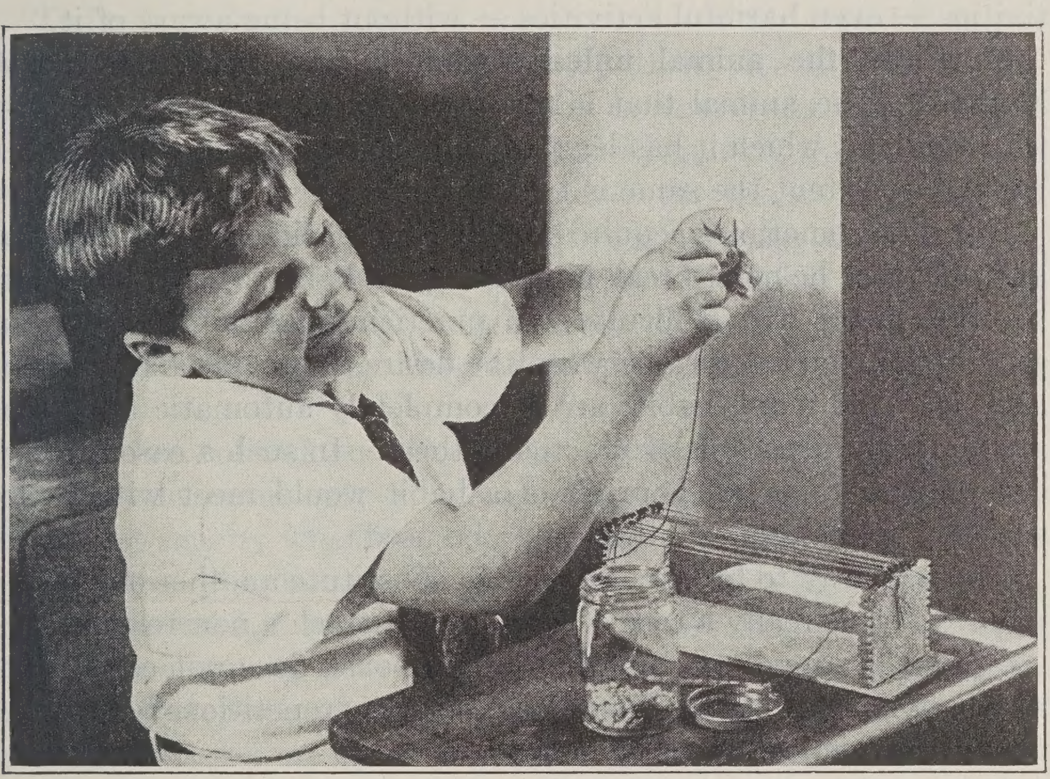
What tool greatly helps man to get experiences? Evidently man is able to store up experiences and make connections between neurons to a much greater extent than any other animal. In the next problem you will see how he differs in structure from the other animals and how this difference in structure helps him. Because of his superiority in these respects he was able ages ago to hit upon a tool which has given him an enormously great advantage over all other animals. Man learned to speak. From speech it was only one step to writing. Because of speech and writing man can learn from others what it took them days or months or years to learn. He can profit by the experiences of others. He can store up these experiences and draw on them to help him reason. His behavior is far more complicated than that of any other animal.

What is the result of complete learning? If you look back to the figures which showed the rat's success in finding its way through a maze on successive days you will see that it accomplished its task faster on the second day than on the first. That is, it had begun to learn. After several days it had learned its way still better. In other words there are all degrees of learning. Now when an animal has repeated an act and has met with reward often enough the learning becomes complete and the act thereafter appears almost like a reflex. A learned act which has been completely learned is called a habit. The fish that rises to the surface of the tank every morning at eight o'clock because you have made a practice of feeding it at that time has learned completely; it has developed a habit.

How does a habit compare with a reflex? A habit may become so firmly established that the impulse is sent through the body with almost as much regularity and speed as in a reflex. That is, it may become automatic. In this respect it is like a reflex act. But, of course, it can never become a reflex and must not be called a reflex, because by definition, a reflex is inborn or acquired without any learning. And there is this other great difference between the two kinds of acts: reflex or instinctive behavior in a certain species of animal is identical in all members of the species, for these animals are born with a complete pattern for reflexes all laid down among their neurons. But the habits of one animal may or may not be like those of its sisters and brothers; the habits, for which pathways are established during the lifetime of the animal, will depend, of course, on the particular surroundings in which the animal lives.

It is impossible and useless for you to try to label each automatic act as either a reflex or a habit. Very frequently when an act is a complicated one a part of it may be learned and another part may be reflex. One overlaps the other. Attempting to label does not add to one's understanding of what is meant by reflex behavior and how it differs from behavior resulting from complete learning.

How is complete learning an advantage to the animal? In the first years of your life you were so busy learning, and learning "completely" or acquiring habits, that you have never been as busy since. You learned to move one leg after the other without holding on and without even so much as thinking about legs. There were many random motions and many unsuccessful attempts before you learned it thoroughly and completely. You learned to use a spoon, even a fork, without having the food fall off. You learned to move certain muscles in your tongue and in your jaws, in a particular way, so that you could say hundreds of different words. If you had been left in the jungle, away from other humans, you would no doubt have learned to make many strange noises but you would never have uttered a real word. Speech had to be learned by imitation through frequent trials and repetitions until it became automatic. It was not inborn. Then you learned to grasp a pencil and draw pictures which no one but you could recognize. At last you learned to form letters so easily that now there are no false motions and you can think about what ought to be put down next while your fingers go right on moving. All of these things and a hundred others that you do daily are habits. In all of them, impulses travel with almost as little obstruction and with almost as great certainty as in reflex acts.



38th Annual Report, Supt. of Schools, New York City

FIG. 259. Has this boy learned how to thread a needle? How can you tell?

You can see the great advantage of learning completely or, as you would say, of acquiring habits. The child who has completely learned to tie its own shoe laces without fumbling can tie up its shoes in a very much shorter time than was first required. Furthermore, the laces stay tied; accuracy or efficiency is developed as well as speed. And after the shoe laces have been tied a few hundred times, the necessary nerve connections are made so easily that the child need not keep his eyes on the job; he can tie the laces while watching the kitten outside chase its tail. The brain cells can be busy receiving other stimuli and sending very different responses at the same time that the act is being performed.

Acquiring habits or learning to do things automatically is obviously helpful to man, but only, of course, if the habit is useful. There is not much advantage in learning to bite off a fingernail with speed and accuracy while your nerve cells are busy picking up stimuli from this printed page. You learn so easily, that is, you acquire habits so readily, that you perfect yourselves in activities — even harmful activities — without being aware of it.

How can the animal unlearn what it has once thoroughly learned? The animal that is not given an opportunity to practice the habit which it has learned will sooner or later unlearn it. To a great extent the same is true of you.

But man sometimes acquires a habit and decides, because it is a bad one, that he must break himself of that habit. It is there that he often meets with difficulty. If practicing the habit gives you satisfaction you are torn between the desire to break the habit and keep it. And many habits are so completely automatic that you are no longer conscious of practicing them. In such a case merely determining to break yourself of a habit would meet with little success. Some other method must be used.

The best way to break a habit is to substitute another one in its place. This is really a case of learning to attach a new response to the original stimulus. But the new response does not come just because you want it to. There must be many repetitions before the new nerve connections are made.

It goes without saying that the oftener you repeat the attaching of a new response to the old stimulus the more surely will you break yourself of your original habit. And since you learn faster when you practice an act at fairly frequent intervals you must keep at it without too much interruption. Obviously, you must not let exceptions occur, for that makes it more difficult to learn the new habit. Furthermore you have surely discovered that the more deliberately and the more eagerly you go about learning anything, the more successful will you be. But, at best, a habit that is well established is difficult to break.

How can you best "learn" a lesson? You may have seen advertisements in newspapers and magazines of courses which are supposed to train the memory. You may have met people who have paid for such courses and who, as a result, believe that they have better memories. But it was not so much their memories that were "trained" as it was a method of study that was given them. They were taught how to learn efficiently and in the least possible time. This is exactly what you need to do when you are learning a lesson. Scientists have discovered a good deal about the best ways of learning a lesson; besides this they can give you some rules for retaining better what you have learned.

To begin with, if you have a hobby you have discovered that you learn a great many things connected with it without effort. The pleasure you get out of your hobby is your reward. You will remember too that the rat learned its way quickly through a maze when there was a reward at the end of the trials. If you set a reward for yourself at the end of your learning or if you are anxious to learn something, you will learn it much more rapidly than if you do not go at it with a strong desire. If you meet with failure (punishment) at the end of your trials you learn very slowly.

You have noticed, too, from your experience with hobbies, that you are successful only if you have a definite aim. Unless you figure out exactly what it is you have to do next for each day that you work on your hobby you do not get very far. Now in learning a lesson a teacher may do some of this planning for you. The teacher can usually plan better than you, but unless you join in with the teacher and unless you yourself try to keep in mind exactly what you are after, you will make little progress; no more than you would if you worked on your hobby without having any definite ideas or plans.

And of course, when there are intervals between your working on and thinking about your hobby, you are obliged to think back to what you did last before you can go on with your new work. In the same way in studying your lesson, if you do not know what you did last or at what stage you arrived in your previous day's work you will learn little of the new work.

Furthermore, you have discovered from your own experience that you memorize, or even learn to do, something much faster if you understand it. Memorizing an English poem goes faster than memorizing a poem in a language which is quite unfamiliar to you. Incidentally, if you understand the material you also retain it longer. Studying a textbook without understanding what you are reading about takes so long that it is impossible for you to do it successfully within a reasonable length of time. And it would be useless to you if you succeeded for you probably would not remember it. *Exercise 9.*

All this was learned through experiments with human subjects. These experiments provide still further hints. Reciting to yourself what you have read, instead of putting all your time into reading and rereading, has been shown to be more economical of time and to help you retain what you have learned for a longer period. Just what proportion of your time should go into the reading and what part into recalling it to yourself depends on the individual and on the assignment. To fix still better what you are learning, it may help you not only to say it to yourself but to write it.

Furthermore, it has been shown that you learn faster and remember for a longer time if you go over the same work *at short intervals* instead of staying at it for a long period and going over and over the same thing at one sitting. If a reading assignment is long and difficult most people learn it better if they study a small bit at a time and learn it thoroughly before proceeding to the next part. But when you divide a chapter or a paragraph into short parts in this way you should begin and end by reading it straight through; otherwise you may not see the necessary connections.

Learning in man is more complicated than learning in the other vertebrates but, luckily for the young student, more is known about it. Applying the suggestions given above and others provided by your teacher will help you to learn quickly and to retain what you learn. *Exercise 10.*

Exercises

1. Study the diagram of the reflex arc. Draw separately (*a*) the receptor, (*b*) the afferent neuron, (*c*) the efferent neuron, (*d*) the effector. Make a second drawing in which you put these parts together so as to make a reflex arc. Add to this diagram the neurons that would be necessary to show that you become conscious of the hot stove.

2. Why is the knee-jerk an example of a simple human reflex? Let someone tap your knee just below the kneecap when your legs are crossed. What happens? Can you keep from jerking your leg when the knee is tapped? Explain and draw a diagram to illustrate what happens.

3. What is another simple reflex response in a person? In a fairly dark room, examine the pupil of a student's eye. Then flash a light into it. Explain what happens.

4. What type of behavior is displayed by the secretion of saliva? This experiment will be especially successful before lunch or late in the afternoon. Display some tempting portion of food or talk about food. What happens? Which receptors are stimulated?

5. How do animals like rats learn? Construct a maze with two or three blind passageways and place some food at its exit. Put a white rat in the maze and note how long it takes to find its way out. Repeat this many times. Is there any indication that the rat is learning? Explain. Keep careful records of the rat's progress.

6. Make several copies of this maze. How long does it take you to trace the path in to the very center by means of a pencil line? How long does it take you the second time? The third time? Keep a record.

7. Using the figures given for the experiments with rats and cats draw a learning curve for each of these animals. Why didn't the animals improve steadily?

8. What type of learning do you display in solving a puzzle, such as the Chinese ring puzzle? Time yourself. Describe the method by which you solved the puzzle. How long did it take your classmates? What method did they use? How long does it take the second time?

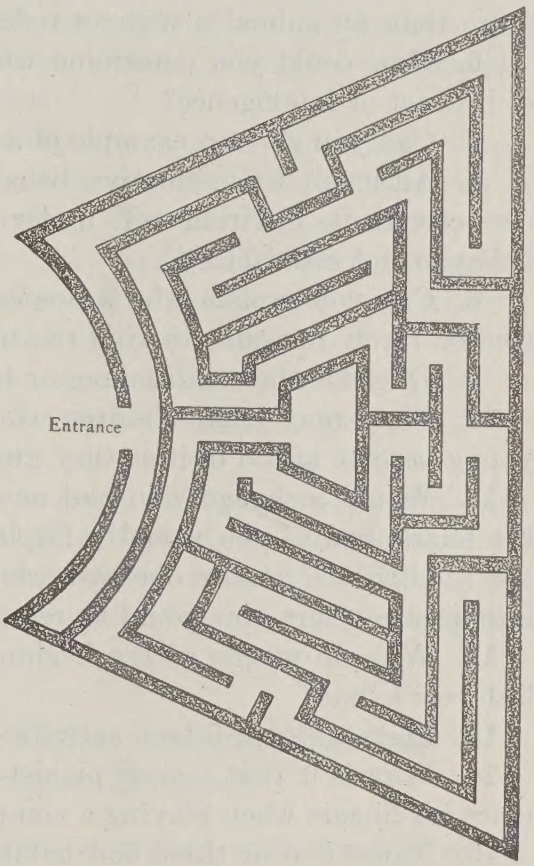


FIG. 260. Hedge maze in the gardens at Hampton Court Palace in England.

9. How is the rate of memorizing affected by understanding? Compare the length of time it takes you to memorize a selection that you understand with one of equal length that you do not understand.

10. Follow the instructions given for proper studying in this problem. Keep a careful record of the progress you make during the term. Do you find that you remember things for a longer time? Do your grades in other subjects show improvement? Is your understanding of the material you are studying better?

Problems for Classroom Discussion

1. List as many human reflexes as you can. How do you know they are reflexes?

2. Trace the exact path of the impulse when food reaches the top of your food pipe and you swallow.

3. Cite some instinctive behavior that is injurious or fatal to an animal. Why has the species not died off as a result of this instinct?

4. "Although without intelligent behavior a man's life would be little more than an animal's, without reflex acts he could not live." Explain.

5. How could you determine whether a particular act is the result of instinct or intelligence?

6. Can you give an example of a conditioned reflex in a child?

7. Although in instinctive behavior an animal generally responds correctly to its environment, under what circumstances is this type of behavior not satisfactory?

8. Can you explain why a domesticated animal that has been badly treated rarely responds to kind treatment?

9. Describe the conditioning or training of some pet.

10. What may make children who were not afraid of the dark when young become afraid of it as they grow older?

11. Would a savage who had never seen doors and levers behave in the puzzle box as you would? Explain. Does this indicate that he has less intelligence? State one case where the same savage would be using intelligence where you would be resorting to trial and error.

12. Why do people at the beginning of a new year frequently write last year's date?

13. Make a list of fifteen activities that have become habitual to you.

14. Why is it that a good pianist does not have to think of where to place his fingers when playing a composition?

15. Name two or three bad habits that you have acquired. Outline exactly how you may break yourself of these habits.

16. A piece worker in a factory earned $12 the first and second week; $13 the third; $14.50 the fourth, and $16 the fifth. Explain in terms of the nervous system.

17. Compare the records in No. 16 with the trial and error figures for the rat. Explain.

18. Why does the far-sighted employer give his employees good working conditions?

19. *Summary.* After you have studied this problem carefully, test your understanding of it by writing two compositions, one to answer the problem question and the other to answer the question, "How may I improve my methods of learning?"

Activities for the Junior Biologist

1. Can you think of any human reflexes that you could demonstrate to your classmates?

2. Study the instinctive behavior of some animals you can watch closely — perhaps ants, bees, spiders, caterpillars making cocoons, birds, and so forth.

3. Could you devise an experiment to determine whether in the behavior noted above there are signs of intelligence?

4. If you have a pet at home, study its behavior and try to determine how much of it consists of conditioned reflexes. Can you explain how these reflexes might have been produced?

5. How can you establish a conditioned reflex in white rats? Train white rats to come for food at some special signal. What will you do to make the rats lose this conditioned reflex? Try it. Keep a record.

6. Devise an experiment to show the "trial and error" method of learning by a cat or dog or some other pet. (*Hint.* Use a puzzle box from which the animal can escape by pushing one side.)

7. Determine to what extent the presence of food at the end of a maze will affect the time in which the animal learns to get out of the maze.

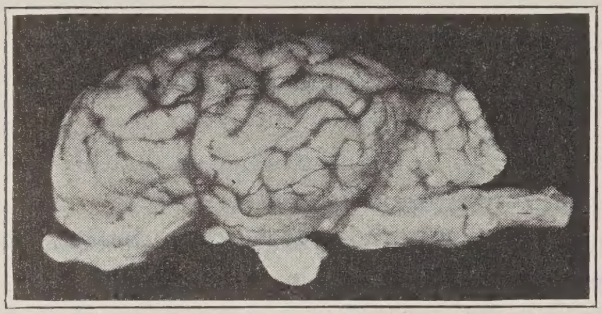
8. Is there any variation in the learning ability of rats? Find out how long it takes several rats to learn to get out of the same maze.

9. Report on various methods of aiding one's memory. You may try some of these methods to see if they actually do help you to memorize things.

Problem 5. How Are the Higher Animals Fitted for Their More Complex Behavior?

How does man's nervous system compare with that of other vertebrates? Vertebrates, as you know, have most of their neurons gathered into a spinal cord and a brain. This brain consists, in all the vertebrates, of several regions, three of which are easily distinguished: the *cerebrum* (ser′e-brum), the *cerebellum* (ser-e-bel′lum), and the *medulla* (me-dul′la); each has definite functions to perform.

In all mammals the brain is much alike; even in man it has the same general make-up, only it is comparatively much larger. Furthermore, the increase in size occurs almost altogether in one region: the cerebrum. It is apparently this greatly enlarged cerebrum that makes man what he is, an animal different from all others in so many ways. His senses are less well developed than those of some other vertebrates; in muscular control and, therefore, in speed and in strength he is far inferior to many other animals; in organs of defense and offense he lags far behind. Yet in spite of all these handicaps he has so far held his own in the struggle for existence because of this well developed cerebrum.



Ward's Nat. Sci. Establishment

FIG. 261. The brain of the sheep is typical of the mammalian brain. The front end (left) is the cerebrum; the smaller part (right) is the cerebellum. Under the cerebellum is the hind end of the brain, the medulla, which narrows down to the spinal cord.

What is the internal structure of the cerebrum? The cerebrum is distinctly made of two parts, a right half and a left. If you cut the brain in two between these halves you will discover that in the very inside there is a small cavity filled with a liquid. The substance around the cavity is whitish in color. It consists of masses of nerve fibers. Some of these come in from the receptors, others run to effectors, and there are many fibers which connect the various parts of the cerebrum with one another. All of the fibers have glistening white coverings or sheaths. It is because of these that the whole region next to the cavity looks white.

The cell bodies to which these fibers are attached lie in the portion outside the white region. This outermost layer is spoken of as the "gray matter" or, better, as the *cortex*. In all the mammals the cortex is in folds or ridges

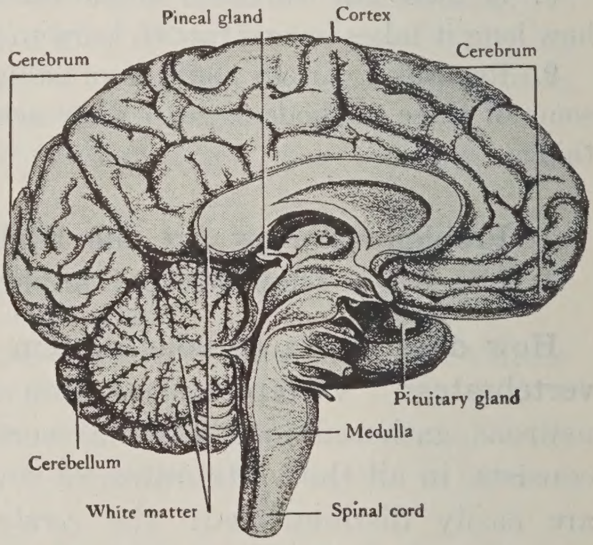


FIG. 262. A section through the middle of the human brain. Compare it with the brain of the sheep. Which of the three regions of the brain show convolutions?

known as *convolutions* (kon-voh-lew′shuns). The cortex of man would cover an astonishingly large surface if it were spread out smoothly. In the other mammals there are fewer convolutions in the cerebrum and they are less deep. *Exercise 1.*

The cortex is very complex, as the diagram shows. The layers containing pyramid-shaped (pyramidal) cells are much thicker in the human brain than in any other. In the lower mammals they are practically lacking. The thickness of these layers varies considerably in different persons, too. Post-mortem examination of the brain of certain types of defectives shows these layers reduced in size. There is reason to believe that the pyramidal cells may be the first to go to sleep and the first to be affected by alcohol.

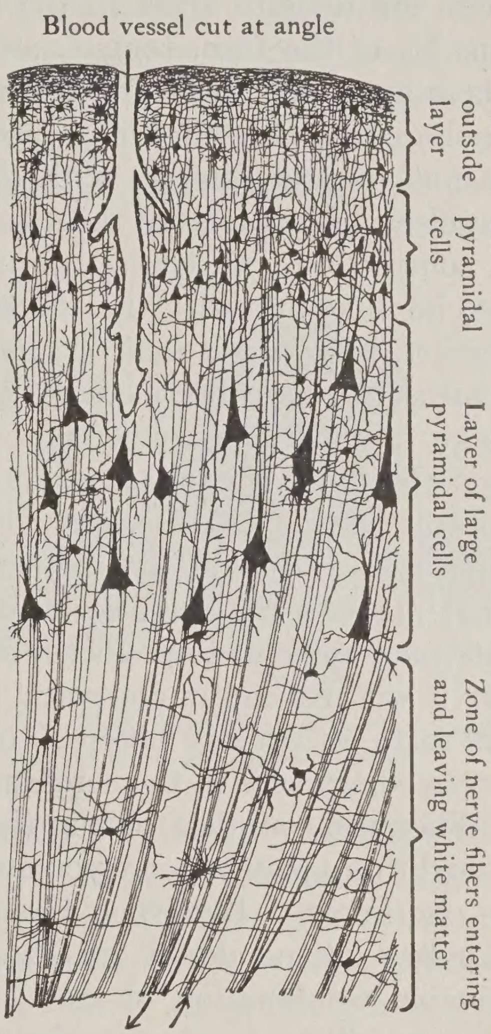

Blood vessel cut at angle
Fibrous outside layer
Small pyramidal cells
Layer of large pyramidal cells
Zone of nerve fibers entering and leaving white matter

FIG. 263. A tiny section through the cerebral cortex of man's brain greatly magnified. Only a few of the cells and fibers are shown. Among the neurons there are other cells which are not shown. What might be their function?

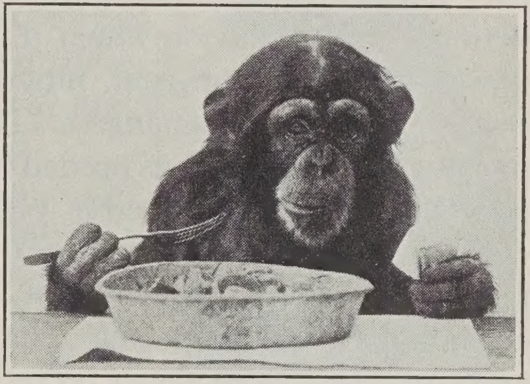
How does man's cerebrum function? All the important receptors send messages directly or indirectly to the cerebrum, which interprets them. You have read that each receptor responds to the proper stimulus by sending nerve impulses to the brain. Those impulses have no meaning unless interpreted by the cortex. Man's sensations are therefore said to depend on the sense organs and the cerebral cortex combined. In general, it is a small portion of the cortex that is directly connected with each receptor. For example, the afferent nerve fibers from the eye end in sensory neurons lying in the back portion of the cerebral cortex. Those from the ear end in a region on the side of the brain above the inner ear, and so on for each kind of receptor.

Besides these regions which receive messages from sense organs there are definite areas in the cortex that control muscles, the muscles of the face, tongue, arm, and other parts of the body. These are called *motor* areas because the activity of their neurons results in motion. In many cases the neurons of the motor areas do not connect directly with the muscles. But they start the impulse which is relayed through other nerve cells and finally ends in contraction. Of course, the neurons of the motor areas must also be linked up with the afferent or sensory neurons. The connection, however, is indirect, for between the motor and sensory neurons there are intermediate cells whose branching dendrites can make innumerable connections. These intermediate cells may stop the incoming messages or may sometimes store them temporarily and change them. Once the impulse gets into these intermediate cells of the cortex it is usually not possible to tell what changes the impulse may undergo. For this reason it is extremely difficult to predict how the organism will respond. To-day it will respond in one way; tomorrow the same stimulus may call forth an entirely different response. This is because of the intermediary cells in the cerebrum.

When the countless cells in the outer layer of the cerebrum are brought into play you say you are thinking. Just what thought is, no one knows. But when thoughts "flash" through the brain, impulses are no doubt traveling back and forth in every conceivable combination of cells. As you read this page certain neurons will be involved and you will have certain thoughts. If you read it again in a month, after the neurons have been receiving thousands of different stimuli and sending countless impulses back and forth, your neurons may make quite different connections; the possibilities are without limit. You may have some of the same thoughts but you will probably have new thoughts, too. One thought sets off another; each new incoming stimulus starts off unexpected nerve impulses. The cerebrum is thus kept busy throughout the life of the individual, at times even when he is asleep; for in dreams there is thinking, although the thoughts may not be reasonable ones.

When a nerve impulse has once traveled a certain path, the path seems to be more readily traveled the next time. It is not known what changes go on in the neuron or at the synapse when a nerve impulse has passed through for the change is not visible, even through a microscope. It is apparently because of these cells in the cortex of the cerebrum that your reflexes may be conditioned, that you can learn by trial and error, that you can store experiences or remember, and that you can reason.

To what extent does the cerebrum in other mammals function like man's? Of course, every cerebrum receives sensations and controls the contraction of many of the muscles. But the more nearly the cerebral cortex of an animal approaches that of man in size and complexity the more nearly does the animal's behavior resemble man's. The chimpanzee has a highly developed cortex although it is less well developed than man's; it is not surprising that it should learn readily and be able to solve simple problems. Other mammals have a smaller cerebrum and a less fully developed outer layer. But they, too, can learn to a limited degree. In fact, it is sometimes astonishing to see to what extent they can remember and make complicated connections. Sir John Lubbock tells of a dog he had trained to read five or six simple words, such as "food," "water," "tea" (of which he was very fond), and "out." When the dog was thirsty he would pick out from a dozen words the one marked "water" and bring it to his master. And the experiment was so carefully performed that there was no doubt that the dog could associate a printed word with each of his particular desires.



Courtesy N. Y. Zool. Soc.

FIG. 264. What has this chimpanzee learned from his human friends?

How did man discover the functions of the cerebrum and other parts of the brain? Disease and accidents to the brain of human beings have taught man much about the functions of the parts of the brain.

Experiments with animals, too, have contributed their share of information, for there is reason to believe that the facts discovered in one vertebrate cast light on the brain functions of other vertebrates, including man. Pigeons have often been used for experiments. In one common type of experiment parts of the bird's brain are removed, one after the other, and the behavior of the bird studied after it has recovered from the operation. For example, when the cerebrum is removed the bird seems, at first glance, to act like a normal bird: it can still hop and move its wings; it can still peck at food and swallow. But closer observation shows that unless its bill comes into contact with the corn the bird will not eat; it fails to see or recognize the food. It fails to initiate any actions. All behavior which it had learned during its lifetime ceases. Only the original, inborn behavior (reflex or instinctive behavior) remains unchanged. Thus it is shown that the cerebrum must contain the neurons needed for seeing and for the other senses, as well as the neurons used in types of behavior that are learned.

If, then, besides the cerebrum the cerebellum is removed, the pigeon can still move the muscles of its legs and wings but accurate control of these parts seems to have been lost. The bird stumbles and staggers and falls over on its side. Each muscle can contract but it can no longer work in cooperation with the others. This and similar experiments provide evidence that it is in the cerebellum that connections are made between the neurons which send impulses to the muscles of the body. These connections are as necessary as are the signals which enable a football team to work as a unit. If there is no teamwork, or *coordination* (coh-ord-in-a'shun), as it is called, the animal cannot behave as a unit. Since there are more than two hundred muscles in a vertebrate's body, coordination is even more important than team play for a football team of only eleven men. The function of the cerebellum, coordination of muscular movement, is a very important one.

But even in the absence of a cerebellum the pigeon can continue to live if it is fed and protected. Its heart beats regularly, it breathes, it still digests its food, and if you touch its foot it still responds by contracting the muscles of the leg. Evidently neither cerebrum nor cerebellum controls these activities. But when now the lowest portion of the brain, the medulla, is removed, the story is a different one. The heart stops beating, breathing ceases, and the pigeon is dead. There can be little doubt that circulation, breathing, and other internal activities depend on neurons located in the medulla. This is the center which directs the important life functions.

How is the functioning of the internal organs controlled? As you have just learned, the central nervous system, composed of the brain, spinal cord, and the nerves directly attached to them, exercises control over two types of effectors, muscles and glands. You may recall that there are two chief types of muscle, striated or voluntary muscle and smooth or involuntary muscle. In general, the central nervous system has direct control over the striated muscle only, not over the smooth.

This fact is of great importance because the muscle found in the internal organs, such as the stomach, intestine, and blood vessels, is smooth muscle. Although the brain and cord play a part in the control of these organs, direct nervous control lies in another part of the nervous system known as the *autonomic* (autonom'ic) or involuntary nervous system.

There are no such large nerve centers in the autonomic system as the brain and cord of the central nervous system; but there are collections of nerve cell bodies called ganglia. There are two chains of ganglia lying near the spinal cord. In some parts of the body the ganglia lie in large groups known as *plexuses*. The plexuses lie buried within the very organs which they control. There are three chief plexuses, the best known of which is the *solar plexus*, which lies just below the diaphragm. It is by means of the ganglia of the autonomic system that connections are made between the internal organs and the central nervous system.

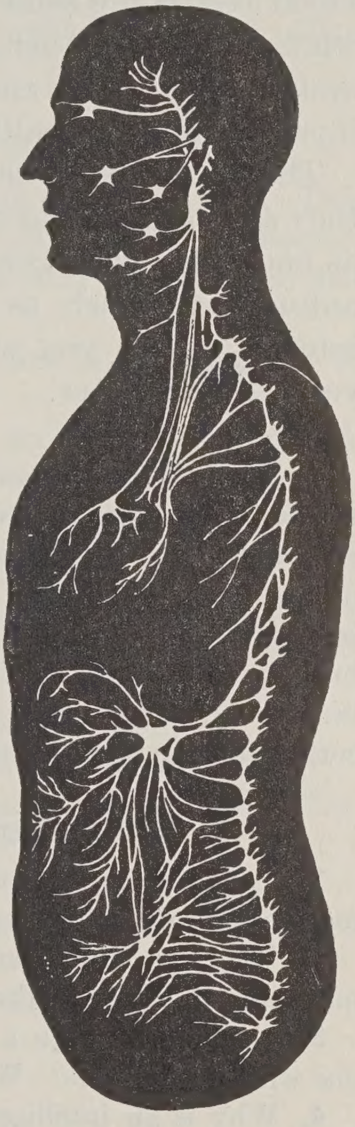


FIG. 265. The autonomic nervous system. Only one of the two chains of ganglia is shown. Can you find plexuses? Where?

You now know why smooth muscle is called involuntary muscle.

You cannot "order" it to contract as you can order the muscles of your arm because its contraction is controlled by the neurons of the autonomic nervous system. Peristalsis in the digestive canal and the contraction and relaxation of the muscles of the small blood vessels are some of the many internal activities that go on whether you wish them to or not. Reflexes through the autonomic system occur all the time so that the body may function normally; if you are in good health you are not made aware of their existence.

The activities of the autonomic system are so complex that they are hard to understand. If you picture the nervous system as one which is concerned with all activities of the body, and the autonomic branch as one which governs the activities of the internal organs you will have a slight understanding on which you can build later.

Exercise

1. What is the structure of the brain of a mammal? If possible, obtain a fresh sheep's brain. Notice the thin coverings over the brain. They are called *meninges* (men-in′jees). Compare with the picture of the human brain (or, better, with a model) and distinguish cerebrum, cerebellum, and medulla. Compare the number of ridges in the sheep's brain with those in the human. Feel the brain; which tissues seem to be lacking? Cut the brain lengthwise from top to bottom. Find the cortex and the white matter. Draw.

Problems for Classroom Discussion

1. Can you give examples to show that man is inferior to some mammals in his senses and muscular control?

2. Why are brains and sweetbread (glands), when eaten, so much more like one another than like beefsteak?

3. Is a person with a large brain necessarily more intelligent than one with a small one? Why or why not?

4. Why is an intelligent person spoken of as one with "much gray matter"? What error in fact is made?

5. Having read the description of the microscopic appearance of man's cortex could you draw the sheep's cortex as you think it must look under the microscope?

6. Without knowing all the details of Lubbock's experiment, what questions would you raise in regard to the scientific accuracy of the experiment? If possible, read the account of the experiment in *The Instincts and Intelligence of Animals* and find out whether Lubbock considered these questions.

7. Why is an injury to the base of the skull particularly serious?

8. Why does a hard blow over the solar plexus cause great pain?

9. *Summary.* List the paragraph titles. Can you answer each briefly?

10. *Unit Summary.* Look through your summary of each problem. Which do you consider the most important problems? Why? Give these a prominent place in your unit summary.

Activities for the Junior Biologist

1. Dissect out the brain, spinal cord, and large nerves of a frog. This takes skill and patience, because the organs are soft and easily damaged. Ask your teacher what instruments to use for bone or try several to find out which works best.

2. Wax or soap or painted papier-mâché models of the brain can be made.

3. If you have a particularly intelligent dog, try to teach him to read, using Lubbock's method. Keep accurate records of your results.

Good Books to Read

Best, C. H. and Taylor, N. B., *The Human Body and Its Functions.* Holt.
Carlson, A. J. and Johnson, V., *Machinery of the Body.* Univ. of Chicago.
Clendening, L., *The Human Body.* Knopf.
Cockefair, E. A. and A. M., *Health and Achievement.* Ginn.
Curtis, W. C. and Guthrie, M. J., *Textbook of General Zoology.* Wiley.
Dashiell, J. F., *Fundamentals of Objective Psychology.* Houghton Mifflin.
Ealand, C. A., *Marvels of Animal Ingenuity.* Lippincott.
Howes, P. G., *Insect Behaviour.* Badger.
Jennings, H. S., *Behavior of the Lower Organisms.* Columbia Univ. Press.
Maeterlinck, M., *Life of the Ant.* Blue Ribbon.
Wheeler, W. M., *Social Life among the Insects.* Harcourt, Brace.
Woodworth, R. S., *Psychology.* Holt.

UNIT VII. HOW DO LIVING THINGS REPRODUCE?

Problems

1. What Is the Simplest Way for Animals and Plants to Make More of Their Own Kind?
2. What Are the More Complicated Forms of Reproduction?
3. How Is Sexual Reproduction Carried On in the More Complex Animals?
4. How Does Sexual Reproduction Take Place in Ferns and Flowering Plants?
5. On What Factors Does Successful Reproduction Depend?

Problem 1. What Is the Simplest Way for Animals and Plants to Make More of Their Own Kind?

Do living things come from lifeless things? For centuries it was believed that some, probably many, kinds of living things could arise by *spontaneous generation.* Spontaneous generation means the developing of animals or plants from lifeless matter, not from some preceding living thing. The Egyptians, for instance, thought that frogs and mice were made from the mud which the Nile deposited in the fields when it overflowed its banks. Even today there are people who think that a horsehair left in water can turn into a snake and that decaying meat will give rise to small worms. But of course many observations have shown that this is not possible. The notion that flies arise from decaying meat was one of the last to go because it was a common experience to see maggots (the larvae of flies) in rotting meat. Redi (Ray′dee), an Italian biologist, disproved this belief shortly after the middle of the seventeenth century in a series of ingenious experiments.

He put decaying meat into several jars. One jar was left open, another was covered with gauze, and a third was covered with parchment, which was so thick that no odor from the meat could pass through. After a time Redi found maggots on the meat in the open jar, maggots on the gauze covering the second jar, and no sign of either maggots or flies near the third, parchment-covered jar. He concluded that there were maggots in the first jar because flies attracted by the odor could enter to lay their eggs. There were maggots on the gauze of the second jar because flies came as close to the meat as they could, and laid their eggs on the gauze. There were no maggots on the parchment because the flies were not attracted to that jar. Certainly, maggots appear only where there are flies present; they do not come out of the meat.

Redi's experiments had been performed so carefully and so many other accurate observations had been made that biologists gradually were convinced that spontaneous generation does not occur. But then, just a few years later, Leeuwenhoek discovered the world of microscopic life and the whole problem was reopened. Here certainly were living things for which spontaneous generation seemed reasonable. The discussion started all over again.

It was ended by the experiments of Louis Pasteur and John Tyndall. Pasteur prepared many bottles of liquid food materials which served as good food for bacteria. After bacteria had appeared in his bottles, he boiled them. This killed the bacteria. While they were boiling he sealed some of the bottles by melting the glass neck; he left other bottles open. When he examined the liquid contents of the open bottles immediately after boiling he found no trace of bacteria. But after these open bottles had been standing in the laboratory for a time, they were discovered to be full of organisms again, while the sealed bottles never seemed to have any. Pasteur broke open a few and let them stand open to prove that the material in them was capable of feeding bacteria. In no time bacteria had appeared and were decaying the liquid food.

Pasteur decided that bacteria could not come from lifeless material but must come from bacteria which were on the dust in the air. To prove this he took some of his flasks to the tops of high mountains where the air was very clean and could not have much dust in it. His opinion was found to be correct; the bottles opened on the mountain tops rarely had any organisms in them if they were sealed before being taken into a dustier atmosphere. Tyndall's experiments were equally convincing. These scientists proved that even the simplest living things can arise only from preceding living things.

How do the ameba and its close relatives reproduce? In examining a slide of amebae, if you are fortunate, you will see an animal making more of its own kind right under your very eyes. It begins by drawing in its pseudopods and becoming less active. Its nucleus, which has come to rest near the center of the cell, divides into two. *Exercise 1.*

Gen. Biol. Supply House

FIG. 266. Paramecium dividing. The lower figure is an earlier stage than the upper. How can you tell?

While the nucleus is dividing, the cytoplasm begins to stream in opposite directions away from the center of the cell. As this continues, the two halves seem to pull away from each other. The cytoplasm connecting the two parts becomes thinner and thinner until finally it is only a thread, which then breaks completely. In about half an hour, there are two amebae, each with its own nucleus, where before you saw only one. This division of the nucleus and the separating of the cell body into two equal parts in a one-celled organism is known as *binary fission* (by′na-ree fish′un).

Each new cell sends out pseudopods, crawls about, engulfs any smaller animal or plant in its path, and rapidly grows into a full-fledged ameba. In fission, therefore, the parent ceases to exist as such; the whole organism is used to make the two offspring. These two are often spoken of as daughter cells, and the parent, as the mother cell. Strictly speaking, there are neither daughters nor mother, but no better names for them have been found.

Fission occurs not only in Ameba and in Paramecium but in most single-celled animals and plants. A cell in a many-celled organism divides in the same way. But such division is not called fission because in this case only a new cell and not a new organism results. The term fission is used only to describe the reproduction of a single-celled animal or plant. *Exercise 2.*

How does the yeast plant reproduce? You know yeast plants, although you may not have thought of them as plants. The compressed yeast cake used for supplying vitamins and for baking bread contains thousands of living single-celled plants. If fed the right kind of food, the yeast plant will grow rapidly and reproduce. When it does so, the nucleus moves to one end of the egg-shaped organism and there divides into two nuclei. The nuclei, therefore, lie at one end. A cell wall then forms between these nuclei; that is, the cell body does not divide in the middle but at one end. The larger part, with its nucleus, is the mother cell and the small piece is the daughter cell or *bud*. This method of reproduction differs slightly from that of Ameba; in the yeast, the cell body divides unequally while in Ameba it divides equally. When an organism reproduces by unequal division of the body, the process is called *budding*.

Unless forcibly separated, the bud remains attached to the mother for some time; in fact, it sometimes remains until it has itself produced a bud, thus forming a small chain of yeast plants. But remaining together seems to be of no importance, for, if shaken loose, the small buds grow larger and reproduce normally. *Exercise 3.*

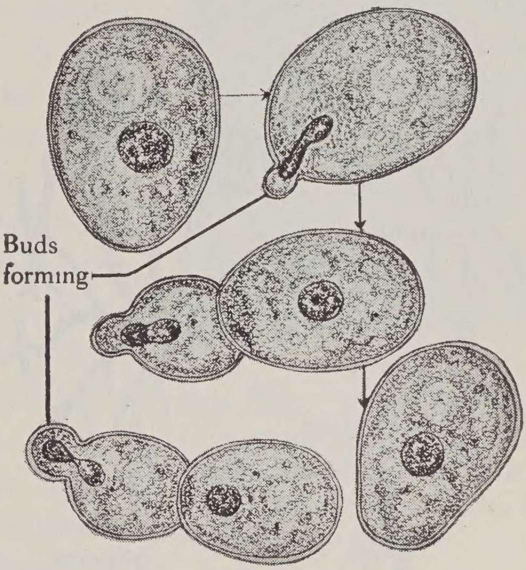


FIG. 267. The common yeast used for baking. How many buds are in the process of forming? Where is the nucleus at this time?

How do simple organisms produce large numbers of offspring at one time? Sometimes a single-celled organism or a cell of a simple many-celled organism splits not into two pieces but into many. In this type of reproduction, as soon as the nucleus has divided, each half divides again. This may go on until there are eight or sixteen or a much larger number of nuclei. A little cytoplasm gathers around each piece of nucleus and in place of the single cell there may soon be a large number of tiny cells. Each cell as a rule develops a thick protective wall. A cell formed in this way is called a *spore*, and the method of reproduction is called *sporulation.* Each spore, no matter how tiny, is capable of existing by itself, for it is a small mass of cytoplasm surrounding a nucleus.

Molds, the fuzzy plants that may grow on damp bread or cheese, reproduce by sporulation. If you have ever examined a mold under the microscope, you know that it is not a simple cell but a more complicated, branching structure. Some of the threads (*hyphae* — high′fee) push down into the substance on which the mold is growing and extract food; some grow upward into the air. The threads that grow upward sometimes swell at the tip. It is in this swollen end that sporulation takes place. There are many nuclei in the tip; when the cytoplasm in the upper end of the thread breaks up each bit contains one or more nuclei. Each tiny cell surrounds itself with a wall; it is a spore. The enlarged end of the thread in which sporulation takes place is called a *spore case* (*sporangium*). It serves as a container for the spores until they are ripe and ready to leave the parent plant. The spores look colorless when seen individually, but in a mass they appear black, green, or yellow, depending on the species of mold. The spores become so numerous that they lend color to the whole plant.

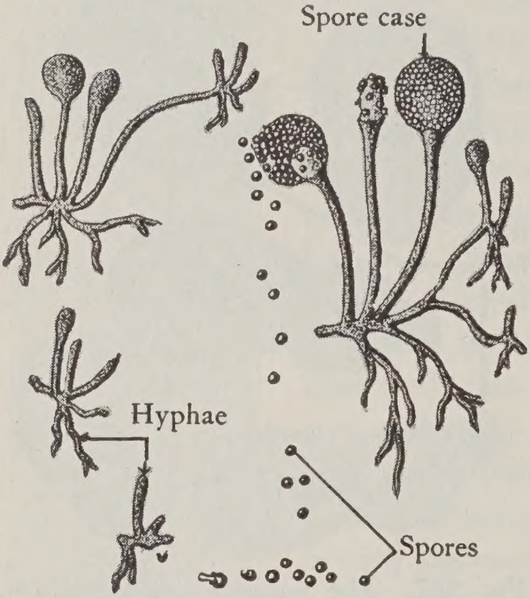
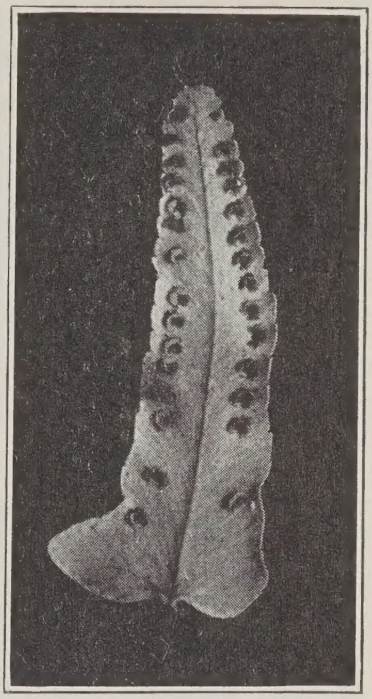


Fig. 268. Spores of the bread mold (Rhizopus) growing into hyphae. What changes occur in the hyphae?

You may have seen spore masses underneath the caps of growing mushrooms, on mosses and, more probably, on ferns. The lower side of the fern frond (leaf) at certain seasons may be marked with brown lines or dots. Out of these you can shake a brown powder which is nothing more than a mass of spores. In the fern, as in the mold, it is only a small part of the plant which sporulates, while the other parts attend to nourishing the plant. And, naturally, when a more or less complex plant forms spores each spore must grow enormously and go through many changes before it will have developed into a new organism like the parent. *Exercises 4, 5.*

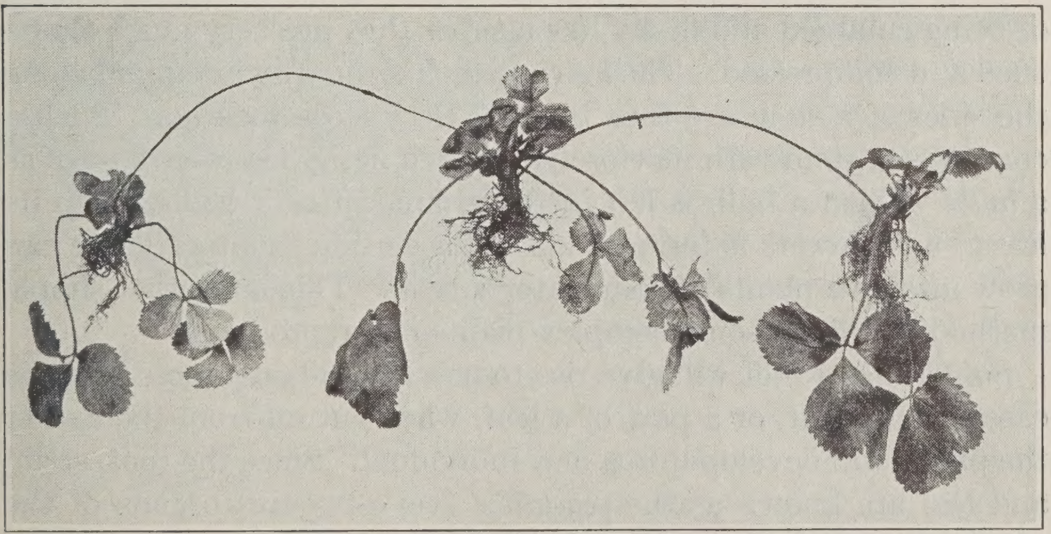
By what simple methods may the complex plants reproduce? A gardener will tell you that the best way to get new geranium plants or ivies or begonias is to cut off a small stem and place it in water or moist sand for some time until it develops roots. Then it can be planted and start life as a new organism. A stem that takes root and develops into a new plant is known as a *slip*, or *cutting*. It is difficult to slip some plants but the expert gardener can get almost any plant to reproduce in this way. Sometimes, too, slipping occurs without man's help. Some willow trees drop twigs which in time become covered with soil, root themselves, and grow into new plants.



Brooklyn Bot. Gar.

Fig. 269. The lower side of a small piece of a fern. Each spot consists of many tiny spore cases. What is in the spore cases?

Sometimes stems form new plants without becoming completely separated from the parent plant. In the strawberry plant a long stem, known as a *runner*, grows along the ground. After it is a foot or two long a short upright stem with leaves



Courtesy Brooklyn Botanic Garden

Fig. 270. Three strawberry plants, two of which have grown from runners.

forms at its end; this takes root and becomes a new strawberry plant. Each plant holds hands, so to speak, with its mother plant and in time stretches out a hand to its daughter. In the black raspberry, a drooping twig, or *layer*, takes root where it touches the ground. This method of producing new organisms is called *layering.*

There are still other plants that use a stem for reproduction, but it is a stem that you are not likely to recognize as such. The white potato is really a stem, although it grows underground and seems to have no leaves. It is considered a stem because it has tiny buds. These buds are commonly called "eyes." The fleshy underground stem is known as a *tuber*. When a piece of the potato is planted, the eyes sprout and grow into new stems and leaves. In frost-free regions many potato plants would develop from one tuber if this were left in the ground.

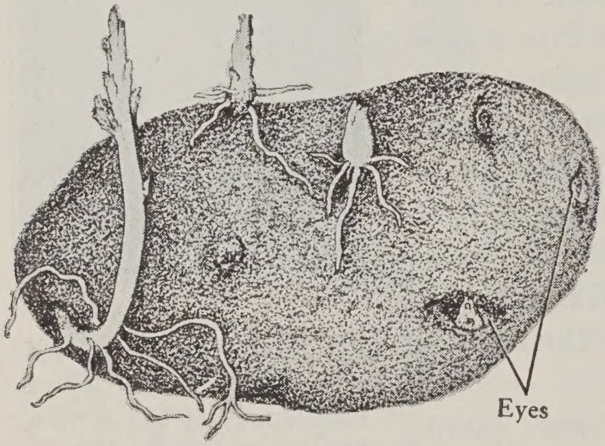


FIG. 271. When he wants a new potato crop, the farmer cuts up potatoes and plants the pieces. What must he be sure to include in each piece? How many eyes have sprouted?

Stems can masquerade in still another way. Sometimes, instead of being enlarged and fleshy like a tuber they are very much shortened and compressed. The leaves which ordinarily are found along the sides of a stem are thus brought very close together. Such a compressed stem with its closely crowded fleshy leaves is known as a *bulb.* When a bulb is left in the ground after it has sent up its leaves and flowers it forms small bulbs as side shoots. These can grow into new plants at some later season. This is another simple method by which some complex plants can reproduce.

Sometimes a root will give rise to new individuals, too. In some cases even a leaf, or a part of a leaf, when cut off from the rest of the plant, will develop into a new individual. Since the root, stem, and leaf are known as the *vegetative* (vej′e-tay-tiv) organs of the plant, this kind of reproduction is spoken of as *vegetative reproduction* or *vegetative propagation. Exercise 6.*

Which animals can reproduce by such simple methods? Most many-celled animals cannot reproduce new individuals from pieces of their bodies. But some of the invertebrates can do just that. Some kinds of starfish are able to drop off an arm which can then grow into a whole new animal. This is not common but there are many kinds of starfish that can reproduce by this means if an arm is removed by cutting. The little flatworm, Planaria, if cut up, will also form several new animals.

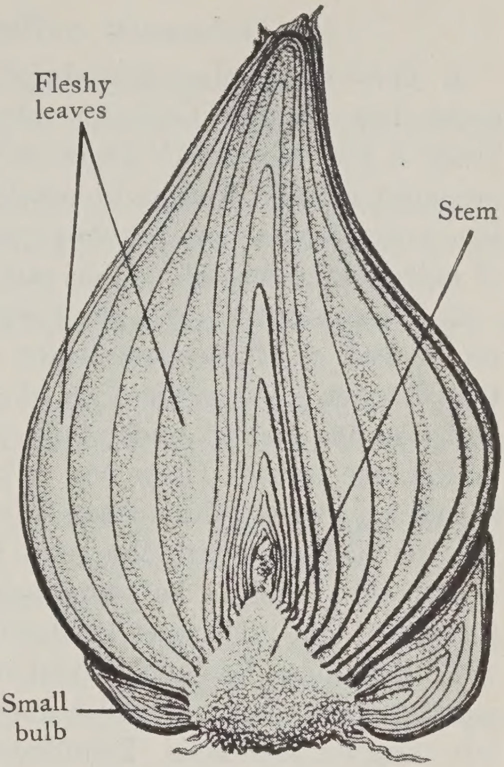


FIG. 272. How many small bulbs have been produced by this onion bulb? Why can a bulb produce leaves and flowers when grown in pebbles instead of in soil?

What is meant by regeneration? Not only will the single arm of the starfish grow into a new animal, but the mutilated starfish will also replace its lost arm. In both cases there is *regeneration* (ree-jen′er-ay′shun), which means producing again. But there is this difference: in the first case the regeneration is more like vegetative propagation in plants. That is, sometimes regeneration results in reproduction, as when a small part grows into a whole new individual; as you just read this happens rarely among animals. The cases of regeneration that are not cases of reproduction are much more common. Many invertebrates are able to restore a lost leg or some other part. Vertebrates cannot regenerate parts so successfully.

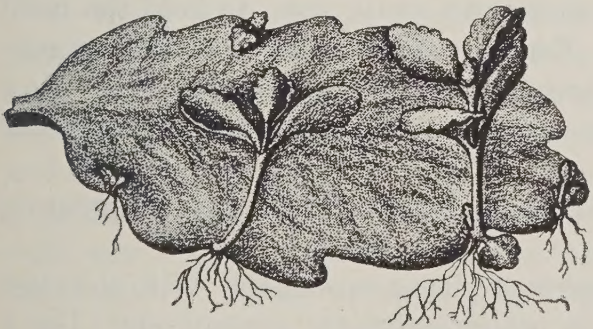


FIG. 273. The Bryophyllum leaf when separated from the plant reproduces vegetatively. How many new plants are growing from this single leaf?

Exercises

1. How do amebae reproduce? Examine a rich culture of amebae under low power. Look for dividing forms. What shape are they? Draw a few important stages in their reproduction. Now examine a prepared slide of division in Ameba. Use the high power. What must you now add to your drawings to complete them? What is this type of reproduction called? (You can use Paramecium or Blepharisma.)

2. How does the yeast plant reproduce? Stir a small amount of yeast into a flask of dilute sugar water. Allow it to stand for a day at room temperature. Mix a bit of yeast cake in half a tumbler of plain water and examine a drop under high power. (You may need assistance in finding the cells.) Draw one or two yeast cells much enlarged. Now examine a drop of the mixture of sugar water and yeast under the high power. Compare with the yeast plants studied first. Why would you expect this yeast to be reproducing? How does it reproduce? Label "mother" and "daughter" cells in your diagram.

3. How does the bread mold reproduce? Place a slice of bread on moist blotting paper in a dish and sprinkle some dust on it. Cover and put away for two days. Examine morning and evening for several days. When threads begin to appear, observe them closely with a magnifying glass and take notes. What color are the threads or hyphae? What do you see on the ends of some of the hyphae? How do these ends change after some days? These structures contain tiny spores that take part in reproduction. What makes the bread mold look black? How does the bread mold get food for all this growth?

4. What does the microscope show about mold reproduction? Examine a bit of the mold mounted in a drop of water under the low power of the microscope. Can you find structures which seem to hold the mold to the bread and absorb food? Examine spore cases. Do you see anything that suggests how the spores escape? Draw what you see. How is this type of reproduction like and how is it unlike that of an ameba? What is it called?

5. Devise experiments to find out the effect of light and temperature on the growth of molds.

6. How may the vegetative parts of plants reproduce? With the class organized into committees try to propagate plants vegetatively. Use a geranium or coleus for slipping (place in water or sand), a potato to show reproduction by the underground stem (tuber), and the bulb of an onion, narcissus, etc. Remove the leaf from a begonia, cover the end of the leafstalk with soil; keep moist. In each case note the length of time it takes for roots to form, or a new plant to appear. How many plants can you name which can reproduce by vegetative propagation?

Problems for Classroom Discussion

1. Of what advantage is fission to the individual Ameba?

2. Why is asexual reproduction more common among simple animals than among complex animals?

3. Of what advantage to the species is reproduction by sporulation?

4. Which can multiply most rapidly, the ameba, the yeast, or the mold? Why? What further information do you need?

5. Why need you buy only a few strawberry plants in order to get a good-sized patch?

6. Why are black raspberry bushes found in dense patches?

7. Why are many willow trees of a single species often found along the banks of a stream?

8. The men who maintain oyster beds used to tear starfish in half and throw them back into the sea. They did this to get rid of the starfish, which eat oysters. What actually happened?

9. *Summary.* Going through this problem page by page, list all the methods of reproduction. Compare them. In what way are they all alike? How does each differ from the others? Could you put all the facts in the form of a simple table?

Activities for the Junior Biologist

1. If you have a rich culture of Paramecium prepare several stained slides to show fission. A simple stain is Lugol's solution. (Potassium iodide and iodine in water.)

2. Make an exhibit of models showing reproduction in the ameba.

3. Devise an experiment to find out how the rate of budding in yeast is affected by the amount of sugar in the solution.

4. What other factors might influence the rate of reproduction of yeast? Try some experiments to find out.

5. Is sporulation the usual method of reproduction in molds? Raise different types of mold on various kinds of food, such as cheese, rye bread, and decaying oranges. Look for spores and hyphae. Report.

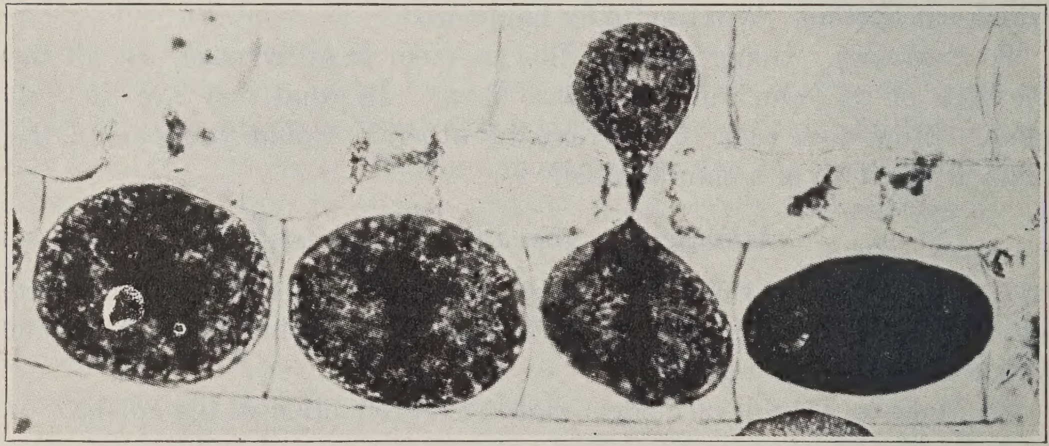
6. Mushroom spore prints are made by standing the mushroom upright over a sheet of white paper in a box (so that the spores will not be blown about). Spray the sheet with "fixatif," using an atomizer.

7. Make a collection of fern fronds showing the various ways in which different kinds of ferns carry their spore cases.

8. Carry out regeneration experiments with Planaria (they may be found in fresh water ponds or obtained from supply houses). They may be cut lengthwise as well as crosswise. They will eat small bits of fresh meat, but do not feed them while regeneration is going on. Be sure your apparatus is clean. Keep a record of your work and report to your class.

Problem 2. What Are the More Complicated Forms of Reproduction?

How do the majority of plants and animals reproduce? In many organisms reproduction occurs by one of the methods described in the last problem. But in the majority of living things, even among very simple forms, the process is more complicated. In these cases, when a cell is separated off from the parent body it will not grow and become a new living being unless it is made active by another cell. The two cells must mix or fuse with one another, nucleus uniting with nucleus and cell body with cell body, in order that another organism may be produced. The cells which do this uniting are known as *gametes* (gam′eats).



Courtesy Ward's Natural Science Establishment

FIG. 274. Sexual reproduction in Spirogyra. Which steps in the process can you find?

The fusion of two gametes is, however, only the first step in reproduction. In fact, the actual fusion seems to be a step in the wrong direction for it is the making of one cell out of two. But you will see that the fusion results finally in the making of a new individual, for immediately, or after a resting period, the new cell divides again and again. The fusion apparently starts the cell division that results in a new individual.

Reproduction which begins with the uniting of two cells is *sexual*, as contrasted with the *asexual* reproduction described in the former problem. That is, reproduction is sexual when the fusion of two gametes is necessary; it is called asexual when fusion of cells need not take place. The great majority of organisms reproduce sexually. Sexual reproduction is found in all kinds of animals and plants from the single-celled up to the most complex.

What is the simplest type of sexual reproduction? To see sexual reproduction in its simplest form you turn, as you might expect, to the lower forms. *Spirogyra*, the green pond scum so common in slowly flowing waters, reproduces by a simple type of sexual reproduction. Although they look inactive, the cells in two filaments which happen to float close to one another may go through important changes. In each cell the distinct spiral chloroplast (or chloroplasts) loses its shape and the mass of cytoplasm begins to shrink away from the cell wall. The filament would no longer be recognized as a spirogyra plant. In the meantime, each cell sends out a projection toward a cell lying opposite to it in the neighboring filament. These projections continue to grow toward one another. When they meet, the cell walls dissolve at the point of contact. This makes a continuous passageway from a cell of one filament to a cell of the opposite filament.

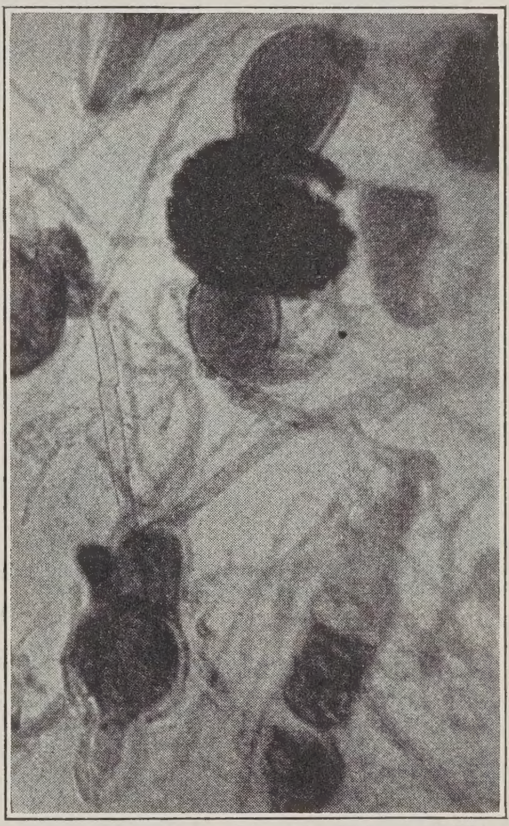


Photo by Nelson S. Kline

FIG. 275. Threads of two bread molds may swell at their ends (lower right corner), meet, fuse, and form a large zygospore (above).

When the bridge has been completed, the semiliquid contents of one cell begin to stream through the passageway into the other cell and the two masses become fused, nucleus uniting with nucleus. Since it fuses with another, each of these two cells is a gamete. The cell which flows across into the other is called the *active* or *supplying gamete;* the cell which remains within its wall is known as the *passive* or *receiving gamete.* Soon there is nothing to be seen of the active gamete but the empty cell wall. Within the other cell wall is the combined mass of protoplasm from both gametes. Because a great deal of water has been lost, this new cell, made of the contents of two cells, does not even fill the space within the cell wall. Still lying within the original cell wall of the receiving gamete, the new cell secretes a heavy coat around itself and is then known as a *zygospore* (zy′go-spore). Gradually the old cell wall enclosing the new zygospore decays and the zygospore sinks to the bottom of the pond.

But this does not complete the story of reproduction in Spirogyra, for no new individual has been formed. So far two cells have united to form one. The second chapter of this story takes many weeks to complete, for the zygospore rests for a long time. Because of its heavy coat it can resist low temperatures and, also, lack of moisture, should the pond dry up. But if conditions become favorable again, the living protoplasm within the zygospore wall becomes active. It bursts open its covering, absorbs water and minerals from the pond water, manufactures carbohydrates and proteins, and grows. When the cell has grown to its normal size its nucleus divides and the cell body follows suit. After repeated divisions there will be a whole new filament or Spirogyra plant. Then the process of reproduction is complete.

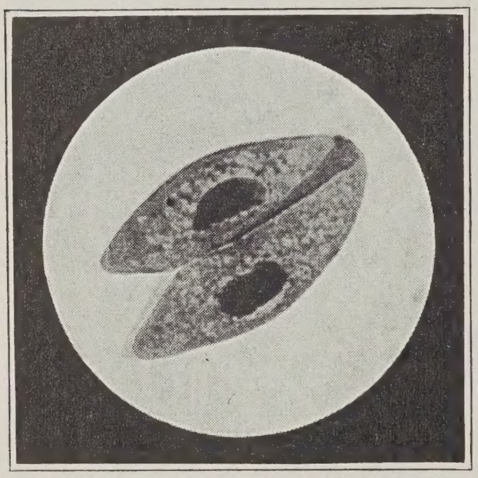


Photo by Nelson S. Kline

FIG. 276. Paramecia sometimes conjugate and exchange pieces of their nuclei. Then they separate and divide.

Since the new individual is formed only after the fusion of two cells this is an example of sexual reproduction. Note that there may be sexual reproduction even though there is no "male" or "female." Sexual reproduction of this type, where the two uniting cells are similar in structure, is called *conjugation*. This simple type of sexual reproduction, conjugation, occurs in some other lower plants and in some animals, too. *Exercises 1, 2.*

What other type of sexual reproduction occurs among living things? There is another type of sexual reproduction, one in which the gametes differ in appearance from one another. In this case one gamete is spoken of as the female cell and the other as the male cell. This type of sexual reproduction may occur among the very simplest living things. There is, for instance, a tiny protozoan that has been found in the stomach of a mosquito. At certain times some of these tiny cells are round in shape and are spoken of as females. At this time there are present also smaller, whiplike cells, each of which has a nucleus; these are the males. A male cell and a female cell fuse, nucleus uniting with nucleus, cell body with cell body.

But again, this is only the first step in reproduction. The female cell having been made active divides again and again, forming a large number of new individuals. Reproduction is thus completed. Incidentally, this protozoan is one of great importance to you, for it may spend part of its life in your blood and give you malaria.

This reproduction in the malaria protozoan is in some ways like reproduction in Spirogyra. As in Spirogyra there is fusion of two cells; the result in both cases is that the fused cell gains the power of dividing repeatedly. That is, both organisms reproduce sexually. But there is this difference: in Spirogyra the two gametes are alike in structure and the fusion is called conjugation. In the protozoan the gametes are unlike and the union is called *fertilization.* There are, therefore, two types of sexual reproduction.

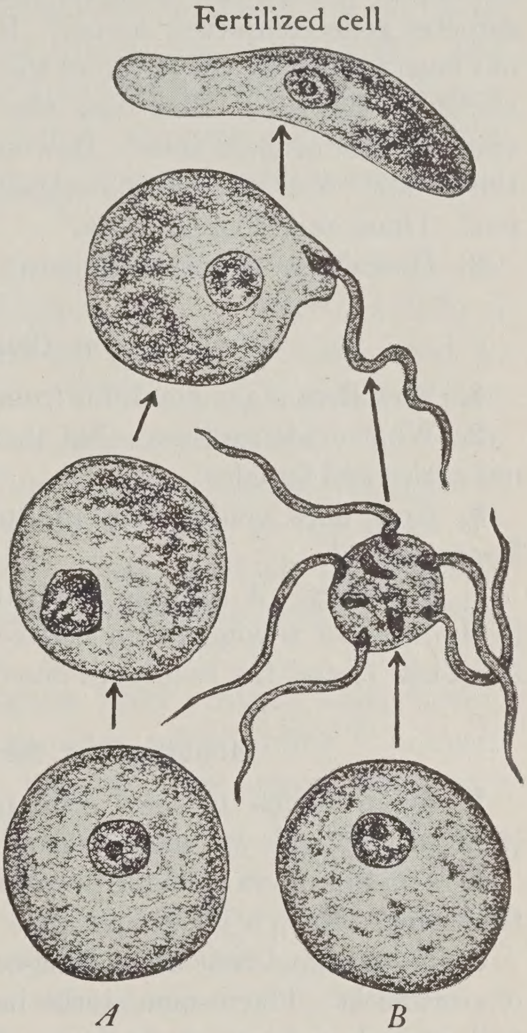


FIG. 277. Fertilization in the malaria protozoan. *A* changes into a female cell. *B* changes into a number of whiplike male cells. What later happens to the fertilized cell?

Exercises

1. How does Spirogyra reproduce? If no living material showing reproduction is available, use prepared slides. Find two filaments which are lying side by side. Look for cells in which a bridge is beginning to form. Find a completed bridge. Do you see any cell bodies crossing from one strand to the other? What can you call these? How do they get across? The other cells are the passive gametes. Have any of the gametes gone completely across? How do you know? Find a cell that has been formed by the fusion of the two gametes. Can you see the fused nucleus? Explain. How does the fused cell or zygospore compare in size with the original cells? How can you tell that the zygospore has a thick wall? You will find no zygospores growing into new plants. Why not? Draw and label all parts.

2. How do paramecia conjugate? Examine prepared slides.

Problems for Classroom Discussion

1. How does a gamete differ from an ordinary cell?

2. What evidence shows that there may be sexual reproduction without males and females?

3. How does conjugation in Spirogyra differ from conjugation in Paramecium?

4. *Summary.* A suitable summary of this problem could be written in the form of a comparison between the simple forms of reproduction (Problem 1) and the two types described in this problem.

Activities for the Junior Biologist

1. Make models to show conjugation in Spirogyra. (Cellophane reinforced with wire will make a good transparent wall.)

2. Can Spirogyra be made to conjugate by lowering the temperature of the water? Keep a jar of Spirogyra in a basin of chilled water.

3. If you have time for a long-continued experiment, raise a culture of paramecia. Place some sterile hay and a few wheat seeds in a flask with enough water to cover them. Inoculate with paramecia from some other culture. After about two weeks, examine the culture each day. How long does it take before you begin to find conjugating forms?

4. Will conjugating forms of paramecia appear if the culture is not allowed to grow old? Devise an experiment to answer this question.

Problem 3. How Is Sexual Reproduction Carried On in the More Complex Animals?

What makes reproduction in many-celled animals seem complicated? Fertilization in the many-celled animals does not really differ from the fertilization that occurs in the single-celled forms.

In both cases, cells which differ in structure come together; nucleus fuses with nucleus and cell body with cell body, forming a new cell.

But in the many-celled animal there must be many cell divisions before the fertilized cell has grown into a new individual. The whole process of growth is further complicated because so many different body parts must develop before the new organism is like its parents. Naturally, it takes much longer for the new animal to be produced.

There is another reason why reproduction in the higher animal seems more complicated. In the higher animals there are cells of many different shapes (differentiation) which are specialized to perform different functions (division of labor). Thus only a part of the animal is used for the function of reproduction; the rest of the body performs the other life functions and merely houses the gametes. To study the gametes it is necessary to disregard the rest of the body and search out the organs in which the gametes are formed. These special reproductive organs will be studied first.

What are the reproductive organs like? Since many-celled animals produce male and female gametes, which differ, it is natural that there should also be male reproductive organs which are different from the female reproductive organs. In vertebrates, the male and female organs are normally found in different individuals. This is not true of some of the invertebrates; worms, and some other invertebrates, have the two kinds of organs in the same individual so that one cannot speak of a male worm or a female worm.

The male cells or *sperm* are produced in an organ known as a *spermary* or *testis* (tess′tiss). The female cells or eggs (ova) are produced in an *ovary* (oh′va-ree). Both spermaries and ovaries are usually in pairs. There are tubes to bring the gametes to the outside, narrow *sperm ducts* and wider *oviducts* (oh′vi-dukts). *Exercises 1, 2.*

What is meant by secondary sexual characters? An animal is called male because it possesses an organ which produces sperm; if it has an ovary and produces eggs it is called a female. Sometimes it is difficult to distinguish a male from a female animal without cutting them open to examine their sex organs. In some

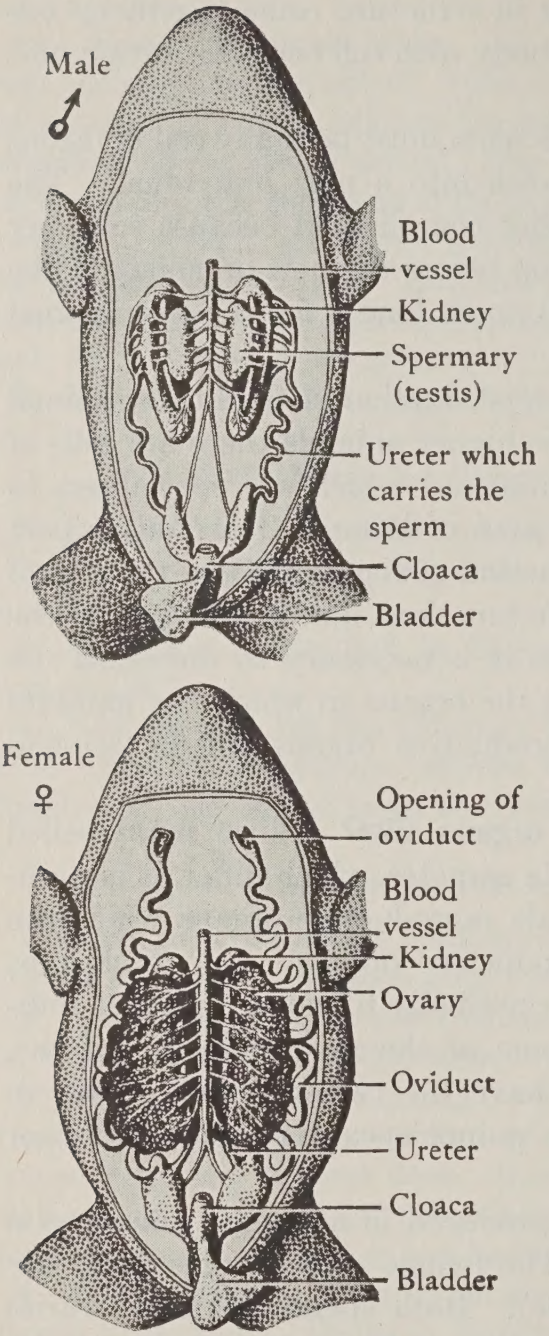
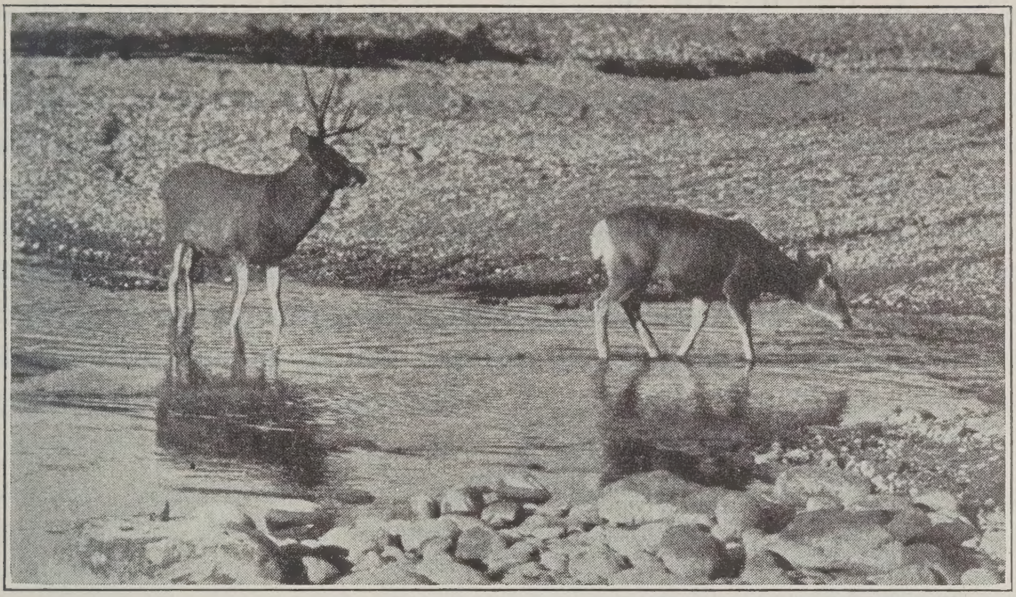

Male
♂
Blood vessel
Kidney
Spermary (testis)
Ureter which carries the sperm
Cloaca
Bladder
Female
♀
Opening of oviduct
Blood vessel
Kidney
Ovary
Oviduct
Ureter
Cloaca
Bladder

FIG. 278. Reproductive and excretory organs of the male and female frog. How do the reproductive organs compare in size? When the eggs are full grown the ovary is much larger.

animals, however, the two sexes are so different outwardly that they can be distinguished at a glance. In some species of birds the feathers of the male are much more brightly colored. Frequently the male of a species is larger and more powerful, although among certain spiders the story is reversed; the male is so small in comparison with the female that he is usually eaten by his ferocious mate.

Differences between the male and the female which are evident without examination of the sex organs themselves are known as *secondary sexual characters.* Among the secondary sexual characters displayed by human beings are differences in bodily size, in strength, in the growth of hair on the face, and in voice. These secondary sexual characters seem to be caused by the action of hormones which are different in the male and female. The hormones are secreted into the blood by special cells in the reproductive organs and are carried to all parts of the body. Thus they are able to cause the differences in bodily structure of male and female. *Exercises 3, 4.*

What is the structure of eggs and sperm? The two kinds of gametes, eggs and sperm, are quite different. Egg cells are usually



Courtesy Canadian Travel Bureau

Fig. 279. What secondary sexual character do you see in the male deer?

spherical (like a ball). They are not always microscopic as you might expect; in some animals they grow to an enormous size. In the hen's egg the yolk is a single egg cell; it is so large because of the great amount of food which it contains. There is in every egg, as in other cells, a nucleus, and a delicate membrane around the outside of the cell body. There is nothing unusual to be seen in an egg cell, except an extraordinarily large amount of stored food in some cases. You see nothing that would lead you to believe that it will grow into a new organism.

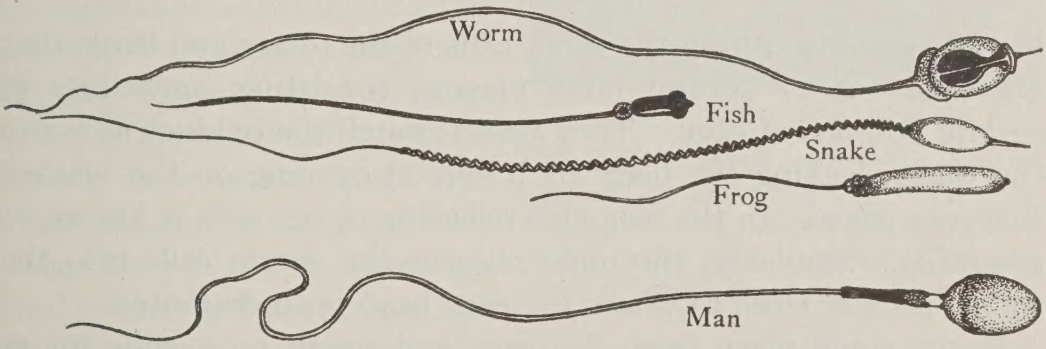


Fig. 280. In what respects do these five sperm cells resemble one another?

The male gamete or sperm cell is very much smaller than the egg. It contains no stored food. In fact, the cell consists of little more than nucleus and membrane. The little cytoplasm that is present forms a thin layer around the nucleus and is drawn out into a long, extremely thin "tail." This tail can lash back and forth and so propel the sperm cell through any liquid. Sperm cells are always so small that they can be seen only through a microscope. In the bird, therefore, the egg is many thousand times as large as the sperm which fertilizes it.

How do the gametes meet one another? There are many ways in which the gametes meet; the methods are different in different organisms. The fish provides a good example of a common method. At certain seasons, often in the spring, the body of the adult female fish gets ready for reproduction. The egg cells develop. They become separated from the other cells of the ovary and leave that organ in one or several huge masses, consisting sometimes of several millions of eggs. They pass through the oviduct and into the water, leaving the body by a special opening on the ventral (lower) surface. In the fish, this releasing of egg cells is known as *spawning*. Similarly, the male releases the sperm cells into the water, usually close to where the eggs have been deposited.

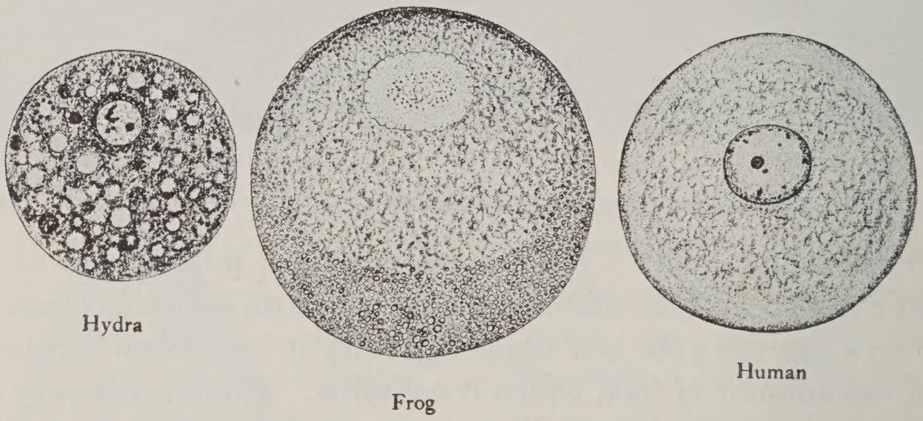
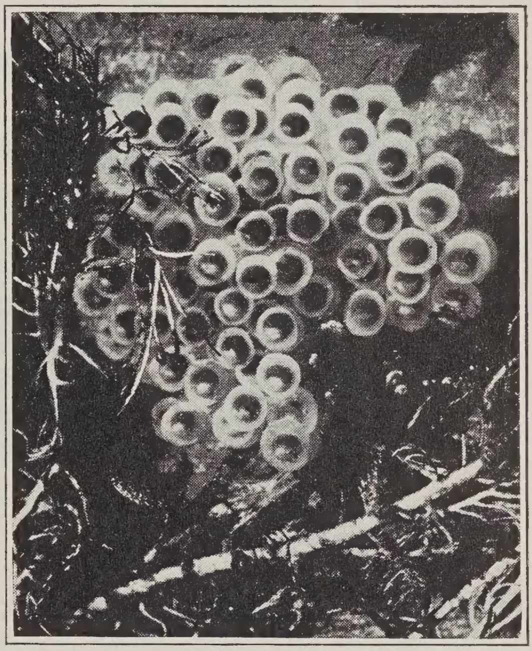


FIG. 281. These eggs are not drawn to scale. In what ways are they alike and different?

If you could place fresh fish eggs and sperm on a slide under the microscope you would see the sperm lash their tails and move actively among the egg cells. Many gather around one egg, either by accident or as a response to a chemical stimulus. Soon one sperm cell is drawn through the cell membrane into the soft cytoplasm of the egg. The sperm nucleus moves toward the nucleus of the egg and combines with it. Fertilization has been accomplished. As soon as one sperm has entered the egg, a tough membrane forms around the egg and other sperm do not enter.

The fertilized egg is called a *zygote* (zy′goat). Every cell formed by the fusion of two gametes is a zygote. Spirogyra produces zygotes, too. But in Spirogyra the zygote has a thick wall and has been formed by the fusion of two like gametes. In such a case the zygote is given a special name (zygospore). The fish zygote cannot be called a zygospore, for it is formed from unlike gametes and it has no thick outer coat.

What becomes of the fertilized egg (zygote)? If the water is of the right temperature, the nucleus of the zygote divides and the cell body very soon divides into two. The two cells remain attached. They do not grow because there is no opportunity to obtain food. The simple compounds dissolved in the water cannot serve as nourishment to animal protoplasm. In the fish, the next steps are difficult to describe. But in all important points the changes are like those described below.



Courtesy Am. Mus. Nat. Hist.

FIG. 282. A small part of the mass of eggs laid by one wood frog. Each egg is coated with a jellylike substance which swells in the water. (*Photo by Mary C. Dickerson.*)

The cells keep right on dividing again and again until, after a few hours, there is a tiny ball of cells. This repeated division without growth of the cells is known as *cleavage* (kleev′aj). Then the cells in the ball arrange themselves so that the ball becomes hollow (a *blastula*). Still floating in the water, if it has been fortunate enough to escape animals looking for food, the hollow ball (or blastula) sinks or grows in on one side so that it no longer looks spherical. A double-walled cup results (the *gastrula*). Shortly, a third layer of cells appears between the first two in the wall. The cup then has a three-layered wall. It does not look much like any animal but out of it, in time, the baby animal is shaped. *Exercise 5.*

How does the three-layered cup develop into a tiny fish? In the fish, part of the original egg does not go through cleavage; it remains as a "yolk sac" or mass of food. The further development of the three-layered cup is extremely difficult to understand. It took years before scientists could give a connected account of the many changes which occur, and without months of study you would be unable to follow their descriptions. But briefly this is what happens. Cell division continues. The cup (gastrula) lengthens and takes on the outlines of a fish. The thousands of cells then arrange themselves into the organs and organ systems of the baby fish. The outer layer of the cup, the ectoderm (ek'to-derm), forms the body covering and the nervous system. The middle layer, the *mesoderm* (mes'o-derm), develops into the muscles, bones, blood vessels, and some other organs. From the inner layer, the *endoderm* (en'do-derm), arises the lining of the alimentary canal. This alimentary canal develops slowly, the mouth forming out of an opening which breaks through at the closed end of the gastrula.

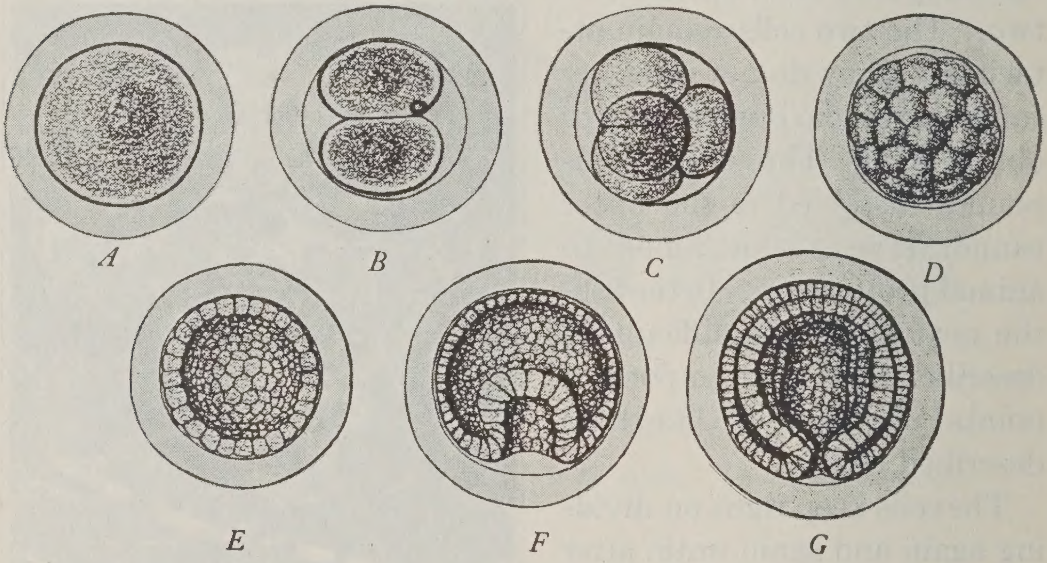


FIG. 283. Development of fertilized egg into gastrula. *A B C D* show cleavage of the egg. *E* shows the hollow ball cut through the middle. *F* and *G* are also sections. What do they show? How do you explain the very slight increase in size?

During all this time no food can be taken in from the outside. The developing animal must live on the nutrients stored in the original large egg cell; there has been no real increase in size. As the animal develops it does so at the expense of the yolk so that gradually the yolk sac shrinks. By the time the animal has organs so well developed that it can obtain its own food and shift for itself, practically all the food stored in the original cell has been used up. This takes about two weeks in some fish; but you must remember that the time varies with different organisms.

The developing organism is known as an *embryo* (em′bree-oh). That is, the fish is an embryo from the time of the first cleavage of the zygote until the completion of the tiny animal with organs of digestion, breathing, locomotion, and so on. When its embryonic (em-bree-on′ic) life is over it swims about as a young fish and obtains food for itself. It is still very small but in other respects is essentially like its parents. The word embryo is used in the same way for other animals as well. *Exercise 6.*

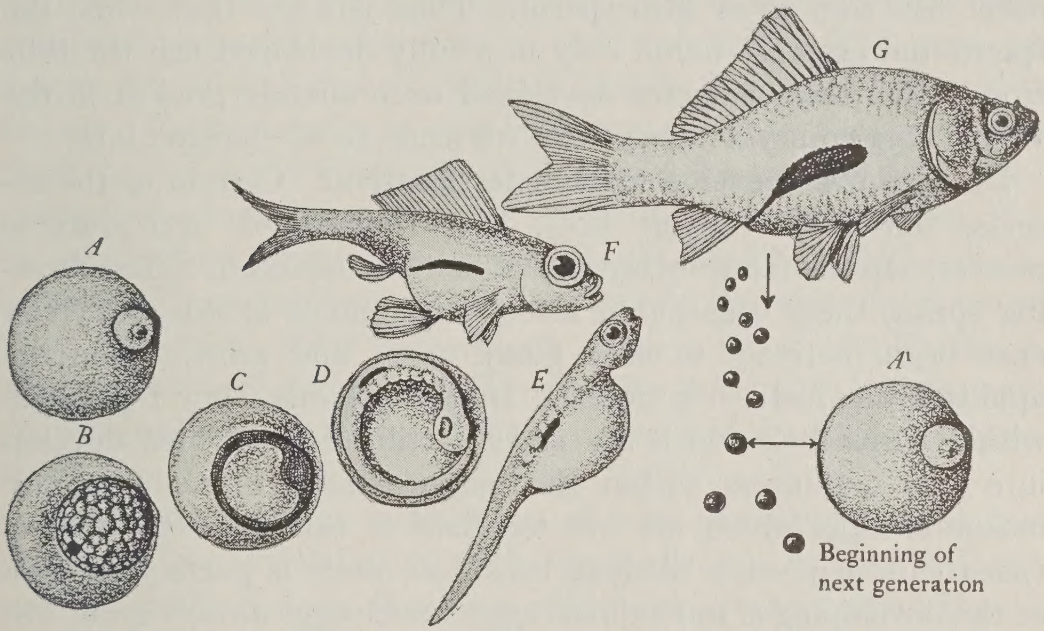


FIG. 284. From fertilized egg, through embryonic stages to adult fish. Fig. *E* shows the "yolk sac," the undivided part of the original egg. Of what use is it to the growing animal? Trace the solid black spot in *B* to *G*. What does it represent?

What provision is made within the baby fish for the next generation? You have just traced the development of a baby fish from the egg cell of its mother and the sperm cell of its father. But in time the baby fish will be grown and will itself become a parent. The generations go right on, one following another. Obviously, organs for the production of gametes must develop in the baby fish just as do organs of digestion and locomotion.

This is what happens: At a very early stage in the development of the embryo, before any cells have begun to lengthen into muscle fibers or change into any of the other tissue cells, certain cells remain almost unchanged within the developing embryo. They still remain as resting cells, unchanged, even after the embryo has become a young fish.

After many months or even years, when the fish has grown to its full size, these cells which have been resting so long a time become active and divide. In some of the fish they grow into eggs; in other fish they grow into sperm. Thus you see that while the sperm and eggs are found only in a fully developed fish the cells from which these gametes developed were already present in the very young embryo. They were set aside to be changed later.

Do eggs ever develop without fertilization? Certain of the insects, the aphids (plant lice), have remarkable reproductive powers. In the fall they lay eggs which are fertilized. The following spring these eggs hatch into young female aphids, which at once begin actively to suck plant juices and grow. Soon the aphids bring forth live young. In other words, they form eggs within themselves which are never fertilized and which develop into new organisms within the parent. Such reproduction by means of eggs which are not fertilized is called *parthenogenesis* (par-then-o-jen′e-sis). Among bees, too, there is parthenogenesis or the developing of unfertilized eggs. Such eggs always grow into male bees. The fertilized eggs develop into the queens (females) and into workers. The workers are neither males nor true females; their reproductive organs, which are those of a female, do not develop fully.

How can eggs be made to develop artificially without fertilization? This problem interested modern biologists because they hoped that they could learn something about the complex processes of fertilization if they could use chemicals instead of sperm. A great scientist, Jacques Loeb, solved the problem almost thirty years ago. After many trials with certain kinds of salt solutions he was able to fertilize the eggs of a sea-living animal by changing them from one solution to another. The eggs never united with sperm; the embryo animals which developed from the eggs had no fathers.

Loeb was able to show that in some cases an adult frog could grow from an egg pricked with a needle that had been dipped in a frog's lymph. The eggs developed as if they had been fertilized by sperm.

Artificial parthenogenesis, as this is called, has helped the biologist to find out what part the sperm plays in fertilization.

How does fertilization in land-living forms differ from that of the fish? Most of the many-celled animals reproduce in much the same way as the fish. There are, of course, minor differences of various kinds. In most cases when animals spend all their lives on land, as is the case with many invertebrates and vertebrates, fertilization cannot take place outside the body. The eggs and sperm, like all unprotected protoplasm, would dry up if exposed to the air. Consequently, in such land-living animals the sperm cells must be put directly into the body of the female. And since the sperm cells depend on their tails for locomotion they must be in a liquid medium when they are introduced into the oviduct of the female. Then they can make their way to the eggs which travel from the ovary down the oviduct. This internal fertilization is also the rule in higher plants. It decreases the chance that the eggs may be lost and thus increases the chances of successful fertilization.

How may internal fertilization change the development that follows? The development of the zygote that is formed by internal fertilization is, in the main, like that of the zygote that is produced by fertilization outside the body of the female. Cleavage takes place, a hollow ball is formed, this turns into a cup (gastrula), and there follow the shaping of the body, the differentiation of cells into tissues, and the forming of organs.

Among mammals, the zygote remains within an enlarged portion of the oviduct, known as the *uterus* (you′te-rus). Here the embryo goes through the stages of development; but its source of food and oxygen is the body of the female. There are complicated organs which link the mother and the embryo together so that materials may pass from one to the other by osmosis through thin membranes. This whole structure is called the *placenta* (pla-sen′ta).

Because of its method of attachment to the uterus the stages in the early development of the mammal appear different from those in the development of the fish. In general they are very similar, but in most cases embryonic life lasts longer. It varies from three weeks in the mouse to two years in the elephant.

Some reptiles, some fish, and a few insects likewise develop within the body of the mother and are born after they are well developed. But these animals, unlike mammals, have no uterus and placenta. *Exercises 7, 8.*

How does the bird develop? In birds fertilization is internal. As the fertilized egg moves along the oviduct on its way to the exterior it is wrapped in protective coverings of various kinds.

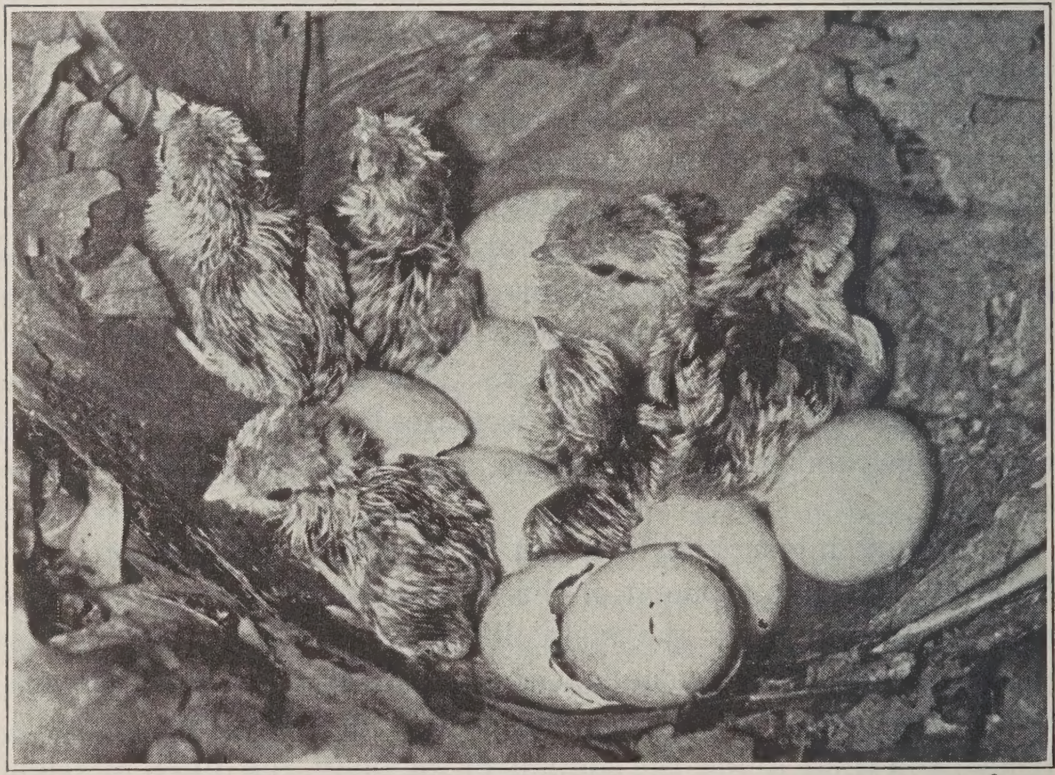
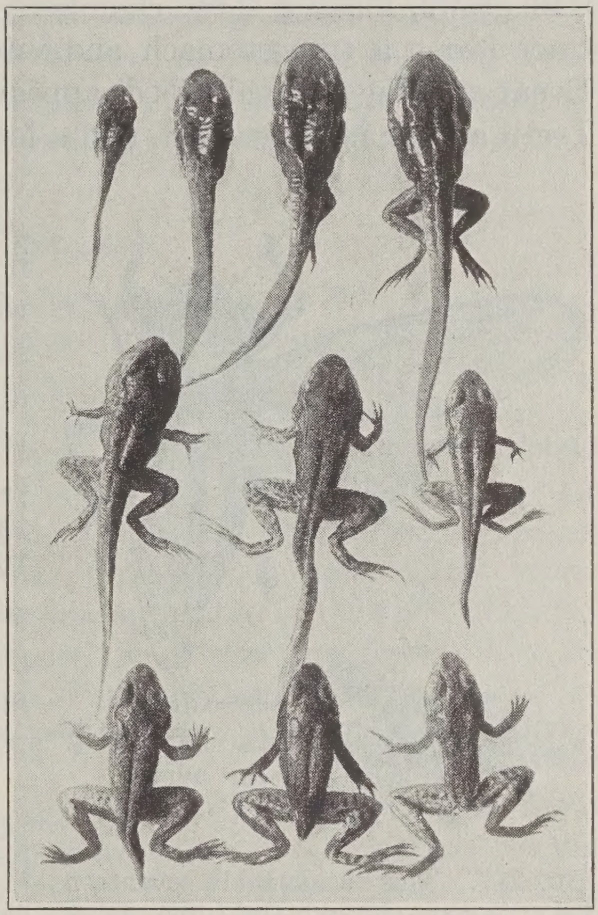


Photo by Frank Gehr

FIG. 285. Young grouse hatching from eggs laid on the ground. How many eggs have not yet been hatched?

The giant egg cell (the yolk of the egg) is surrounded first by the white of egg (albumen). This not only helps to protect the developing embryo but later serves as food for it. As the egg moves on, the oviduct secretes about it two thin, tough membranes and lastly a hard shell. By the time it is laid the egg is well protected.

In the meantime the zygote has begun to divide, but by far the greater part of the development occurs after the egg has left the body of the mother. In order that the zygote may develop normally into an embryo the egg must be kept warm and at a constant temperature. In almost all cases the bird sits on the eggs during the incubation period, which lasts about three weeks. At the end of this time the food from both yolk and albumen has been absorbed and the organs of the young bird have been formed. By means of its bill it cracks the shell and pecks its way out into the world.



New York Zoological Park

FIG. 286. A tadpole changing into a frog. The smallest form is no longer an embryo. Why? What is the first sign of its becoming a frog? What is the last change to occur?

How is the period of development lengthened in some animals? When the embryo which develops from the frog's egg is fully formed it does not look like its parents. You call it a tadpole or pollywog. It looks more like a fish than a frog. It wriggles about in the water, breathing by means of feathery structures on the outside of the body just back of the head. They are gills, which are used like the internal gills of a fish. At first the tadpole has no real mouth, only an opening with a ring around it. This ring becomes attached to water plants by suction and food is sucked in. Soon the tadpole begins to move its tail back and forth very rapidly and to propel itself through the water. Gradually the sucking mouth part is replaced by a true mouth with horny jaws. The external gills shrink and in the meantime internal gills have formed. It is now very active, eats a great deal of plant food, and grows rapidly.

After living this way for several months two lumps appear near the hind end of the tadpole's body, one on either side in front of the tail. Slowly legs push out here. If you cut the tadpole open at this time you would find little arms already formed under the skin at the anterior end. Its organs of digestion and circulation would be different from those of the parent frog but at about this time they begin to undergo changes. Within the two-chambered heart a wall grows, making three chambers. The long, coiled digestive tract forms a true stomach and intestine. Lungs are forming. Eventually the internal gills disappear; the tail becomes absorbed. Teeth appear in the mouth, and a long tongue. The animal now feeds on insects and spends part of its life on land. When it is swimming and floating in the water it must come to the surface regularly to breathe air. In its habits and its appearance, it is a very different animal from the tiny tadpole that hatched from the egg. When striking changes of this sort occur between the embryo stage and the adult the development is called a metamorphosis. *Exercise 9.*

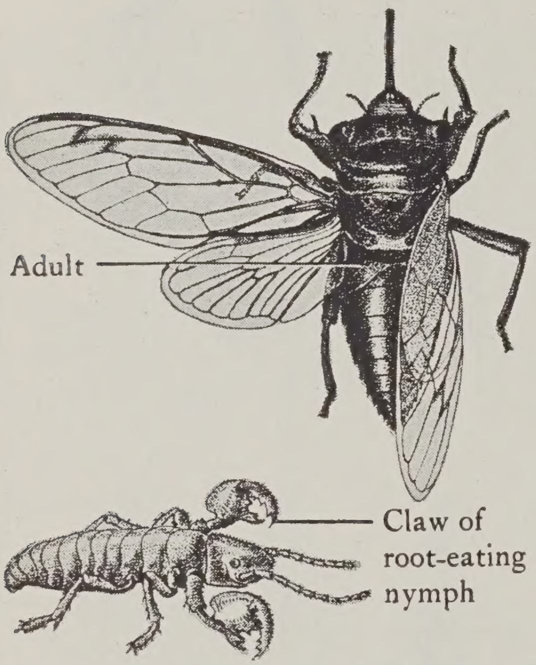


FIG. 287. This cicada takes seventeen years to pass through the three stages of its life history. The nymph lives underground. How does it differ from the adult?

Among insects metamorphosis is the rule. Sometimes it is what is known as *complete metamorphosis,* in which case there are four quite distinct stages: egg, larva, pupa, and adult. Sometimes the changes taking place are not very marked, as in the development of the grasshopper. This is called *incomplete metamorphosis.*

How do most animals reproduce? Although you have studied in detail the reproduction of only a few of the complex animals you must realize that the vast majority of many-celled animals reproduce in much the same way. With few exceptions they form sperm and eggs in organs known as spermaries and ovaries. Since, in most species, these organs are in separate individuals you can speak of a male and a female, whether it be a crayfish, a mosquito, a frog, a mammal, or any one of many other kinds of animals. In all these, a single sperm cell must fertilize an egg cell if a new individual is to be formed. In most water-living forms this fertilization is external; in land-living animals it is usually internal.

The formation of a zygote by fertilization is always followed by cleavage, differentiation, and the shaping of a new animal out of the mass of cells. The more complex the animal, the longer will this process take. But fundamentally it is the same in the many kinds of animals, both invertebrate and vertebrate.

Exercises

1. *Demonstration.* The reproductive organs of the frog. Study freshly killed, or preserved, male and female frogs. Compare the external appearance. Can you distinguish male from female? During the breeding season a difference can be noted in the hands. What is it? How can the sexes be distinguished after dissection? How many spermaries has the male? In what part of the body do they lie? The sperm ducts are too small to be seen. They lead the sperm cells into the kidney whence they are carried to the exterior. How do the egg-producing organs (ovaries) of the female differ from the spermaries of the male? Can you find ducts which might be oviducts? How many are there? Why are the oviducts so much larger than the sperm ducts? Study some of the eggs from the ovary. Note the color. Estimate the number of eggs in one ovary.

2. How do the reproductive organs of the hen differ from those of the female frog? Examine the organs taken from a drawn chicken. Do you find eggs? How many? What size are they? What indication is there that the eggs are not all produced at one time? Is the same thing true of the frog or fish? How many ovaries and oviducts do you find? Where must the white of egg and the shell come from? Where must the egg be when it is fertilized? How do you know?

3. How may the sexes be distinguished in some birds? Examine pictures or specimens of both sexes of various species of birds. What differences do you note between male and female? If pictures are available trace the outline of the birds through glass and color with crayons.

4. What is the structure of a sperm? Crush the spermary of a freshly killed frog (or the seminal vesicle of an earthworm) under water. Examine a drop under high power. Describe what you see. Examine a prepared slide of mouse or rat sperm. In what ways are these types of sperm alike?

5. What are some of the early stages in the development of the fertilized egg? Use prepared slides showing the early development of a starfish or sea urchin. Find and draw one, two, four, and many-celled cleavage stages. How do they compare in size with the fertilized egg cell? Explain. Find a clear section of a hollow-ball stage; of a cup stage. Draw. How many layers of cells does the wall of the cup (gastrula) contain?

6. *Demonstration.* Development of the fish. Using a museum preparation or chart study the changes which occur in the fertilized egg. Examine the egg closely for the first indication of the formation of an embryo. At this stage has the egg changed in size or shape? As the embryo grows larger, what happens to the egg?

7. What is the structure of a hen's egg? Crack a raw egg into a saucer. What do you find directly under the shell? How many membranes do you find? Examine the shell and the membranes at the blunt end. What do you discover? The yoke is the egg cell. What makes it so large? Do you notice a tiny white spot on the yolk? This is the protoplasm and nucleus, which receive the sperm cell. Of what use is the white of egg? The shell? The membrane? Compare with starfish or sea urchin egg (prepared slide), or frog or fish egg from a dissected animal. How does it differ?

8. *Demonstration.* Development of the chick. Stained microscope slides may be examined with a hand lens for the early stages. Look for the heart and the beginnings of the nervous system (thirty-six hours). Later stages show the limb buds and the eyes. A museum preparation or a chart will show the later development of a chick. Which part is proportionately large in the early stages? At what stage does the embryo begin to look like a bird? When do the feathers appear? When are you sure that it is going to be a chicken and not a duck?

9. *Demonstration.* Development of a tadpole into a frog. In the spring gather frogs' eggs and watch development. (Water must be changed frequently.) At other seasons, examine museum preparation or chart. Why is the young tadpole not considered an embryo? How does it feed? Describe the changes in its feeding and locomotion that take place as it grows older. Which legs appear first? Look for the legs just before they break through. How does the tail disappear? Explain.

Problems for Classroom Discussion

1. Explain division of labor as it applies to reproductive organs.

2. Why are "secondary sexual characters" spoken of as secondary? Give as many examples as you can think of in different phyla and classes.

3. The female bird is usually less brightly colored than the male. Is there any advantage in this?

4. In the case of other animals showing secondary sexual characters can you state an advantage to the animal?

5. What is the advantage in having all the stored food within the egg instead of having it equally divided between sperm and egg?

6. Far more sperm are produced than eggs. Of what advantage is this to the species?

7. Which is better protected, the zygote of the fish or the zygote of Spirogyra? Explain.

8. Why does the zygote of the fish or frog need stored food more than the zygote of Spirogyra?

9. Of what advantage is the thick membrane that forms around an egg as soon as it is fertilized?

10. A certain amount of heat is necessary for the development of vertebrate eggs. Explain how an animal of each of the five classes provides for this.

11. Why can a frog which goes through a metamorphosis get along with a smaller egg than a bird?

12. Why can mammals get along with small eggs?

13. *Summary.* To answer the problem question outline the problem by using such headings as the following: Reproductive organs; Secondary Sexual Characters; Gametes; Fertilization; Development; Parthenogenesis; Types of Reproduction in Different Animals.

Can you compare various animals with respect to each of these topics? If so, you have a good idea of sexual reproduction in animals.

Activities for the Junior Biologist

1. If you can have the use of an incubator study the development of the chick. Start with twenty-four eggs and open one every day. Perhaps someone could make models of the different stages.

2. Guppies and some other tropical fish bear the young alive. You will find it interesting to raise some.

3. Pigeon raising is easy if you have the use of a roof. Get instructions where you buy your first pigeons.

4. If you are interested in turtles or snakes try to raise some.

5. If you have an opportunity to observe a litter of kittens, puppies, white mice, or rats watch for indications of parental care. To what extent are the young taught by their parents?

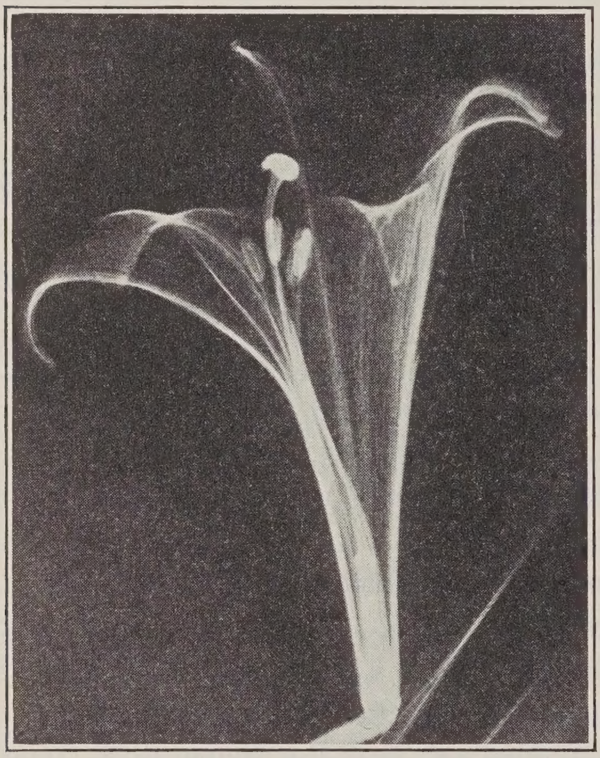
6. Report on the work of Dr. Jacques Loeb on the artificial fertilization of the eggs of the sea urchin.

7. Raise tadpoles from frogs' eggs.

8. Could you make wax or plaster models of the cleavage, blastula, and gastrula stages of some simple form such as the starfish?

Problem 4. How Does Sexual Reproduction Take Place in Ferns and Flowering Plants?

What is a flower or blossom? The large majority of plants you see about you ordinarily, the many kinds of trees, the shrubs, and the various species of grasses in lawns and fields, all bear blossoms, although you may never have noticed them. The blossom is often spoken of as the reproductive organ of the plant. But it does not correspond to the spermary or ovary of an animal. It is far more complicated.



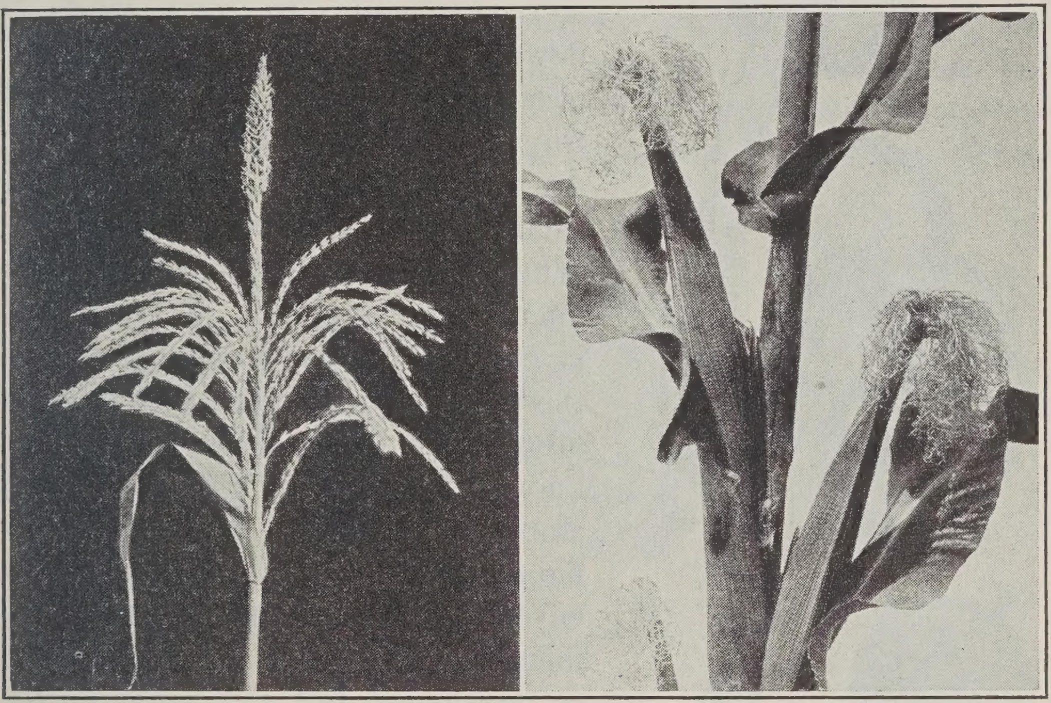
Courtesy Gen. Elec. X-ray Corp.

Fig. 288. This X ray of a lily shows the six parts of the floral envelopes, and inside of these the stamens and a single pistil.

Blossoms have many variations. In the lily there are six brightly colored leaflike parts in two circles, known as the floral envelopes. In many flowers the outer circle (*calyx*) is green and the parts are known as *sepals*. The inner circle (*corolla*) consists of bright *petals* which often are larger than the sepals. Some flowers have their floral envelopes so reduced that at first glance you would not know that you were looking at a flower. There is also considerable variation in the *stamens* (stay'mens), which are the threadlike parts within the petals, and in the *pistil*, which is found in the very center of the blossom. In certain plants, such as the willow, corn, and others, some of the blossoms lack a pistil, while others lack stamens.

It is plain that a flower may be very simple in structure; it may consist of very little more than a few stamens, or, in other cases, of a pistil or two. But at least one or the other of these structures must be present to make a flower. For this reason, the stamen and pistil are called *essential organs.* Both are essential to the process of reproduction. *Exercise 1.*

In what way is the stamen essential to reproduction? The stamen is always composed of a more or less slender stalk (filament) with a bulky pollen case (*anther*) on top. If the stamen is shaken after it is ripe quantities of powdery *pollen* fall from this case. Each tiny pollen grain, when ripe, has two nuclei, so that there are really two cells within its thick wall. These cells are not separated by a membrane, however. If the pollen grain happens to fall on the top of a pistil of a flower of the same species a tube grows out of the grain. This is the *pollen tube.* The two nuclei move into the tube when it begins to form. In the meantime, one of the two nuclei divides again to form two *sperm nuclei.* There are thus three nuclei. One of the sperm nuclei with its surrounding bit of cytoplasm is the true male gamete, corresponding to the sperm cell of the animal. Its twin sperm nucleus has a special function to be described later. The third nucleus, known as the *tube nucleus,* always remains at the tip of the tube. You need not concern your-



Courtesy U. S. Dept. of Agriculture

FIG. 289. The corn plant has tiny flowers with stamens. These are gathered together on the "tassel" shown on the left. The ear of corn is a group of somewhat larger flowers with pistils. They are wrapped in the husks; only the tips stick out.

selves with these extra nuclei now; the important thing is that you have found the male gamete (the sperm) which is needed for sexual reproduction. *Exercises 2, 3.*

Where can you find the female gamete? If you cut into the thickened lower part of the pistil, the *ovary*, you will find *ovules* (oh′vules) within. The word ovule means a little egg but this name is badly chosen, for an ovule is not an egg at all. In some kinds of flowers there is only one ovule; in others, there are many hundreds of tiny ovules crowded into the ovary. An ovule, therefore, must be very small, sometimes even microscopic. When you examine one under the microscope, you will discover that it consists of many cells. Some of these cells form two protective coats around one very much larger cell known as the *embryo sac.* This embryo sac divides in time, as the figure shows, usually into eight cells. Often the cells are not separated by membranes, so that it is one mass of protoplasm but with eight nuclei. One of these nuclei with its surrounding cytoplasm is the *egg cell,* or female gamete. Two of the other nuclei usually fuse and move to the middle of the embryo sac. This double nucleus will be referred to again. The important thing is that you have found the egg cell, or female gamete.

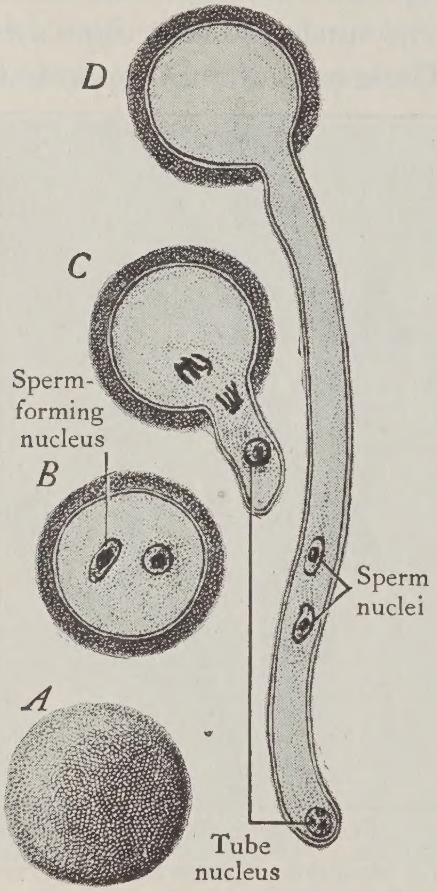


FIG. 290. *A*, pollen grain much magnified. How many nuclei are there in *B*? What is happening in *C*; in *D*? Where is the true male gamete?

Thus you have found the two gametes, the sperm hidden within the pollen tube and the egg cell within the ovule. They are both so deeply buried that it is not an easy job for the plant to bring them together. Yet obviously they must at some time fuse with one another or they could not take part in reproduction and be called gametes.

How are the gametes brought closer to one another? The first step in bringing the sperm and egg together is to bring the pollen and ovule closer to one another. Since the ovule lies buried deep within the pistil the pollen grain can get no nearer to it than the outside of the pistil.

The top of the pistil, the *stigma*, is often hairy and sticky, thus affording a convenient resting place for the dustlike pollen grains. Sometimes the pollen comes to the stigma from the stamen of the same flower; sometimes it is carried by wind or by insects from the stamen of another flower of the same kind. In one case the transfer of pollen from the stamen to the pistil is known as *self-pollination;* in the other as *cross-pollination.* In this transfer much pollen goes astray; only a small part of all the pollen actually reaches the stigma of a pistil of the right flower. *Exercises 4, 5.*

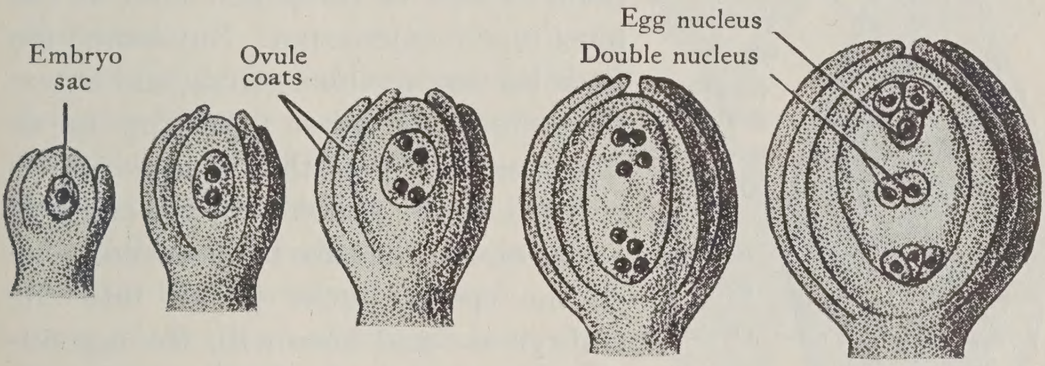


FIG. 291. A young ovule growing into a larger ovule. The embryo sac within also grows. What happens to its nucleus?

How does the male gamete finally fuse with the female gamete? Pollination merely brings the pollen to the stigma. In most flowers the stigma is separated from the ovary by a part of the pistil called the *style.* Even when pollination has been accomplished, the male gamete is therefore still far from the female gamete. But the pollen grain absorbs some of the sugary fluid secreted by the cells of the stigma and grows rapidly. You saw in an earlier paragraph that it forms a tube with three nuclei. This tube grows longer and longer, going down among the cells of the stigma and the style. It can do this because it has enzymes which dissolve the cells which lie in its path.

The growth of the pollen tube may take from several hours to many days, depending on the length of the style and on other factors. If pollination has been successful, hundreds of pollen grains will have fallen on the stigma. Most of these form their tubes and if the ovule case contains many ovules (each of which contains an egg cell) just as many of the tubes will be needed, one for each egg cell. But in most cases, no doubt, more grains settle on the stigma than there are ovules; then the first pollen tube to reach each ovule is the only tube to take part in fertilization.

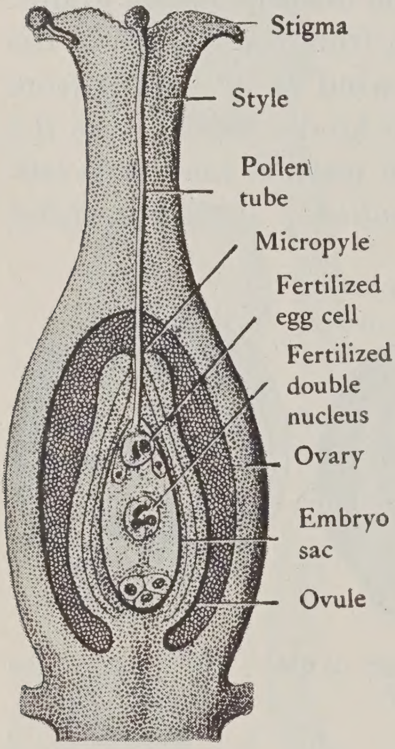


FIG. 292. Section through pistil after fertilization has occurred. Only one ovule and one complete pollen tube are shown. Compare with diagrams of ovule and pollen shown earlier in the problem.

Each ovule has an opening (the *micropyle*) which sometimes lies, from the point of view of the pollen tube, at the most inconvenient spot. But some tube finds its way to this opening and enters the ovule; the other tubes dry up or disappear. When the embryo sac is reached by the pollen tube the cell wall at the end of the tube is dissolved. One of the sperm nuclei passes into the embryo sac and fuses with the egg nucleus, producing the fertilized egg cell.

What happens to the second sperm nucleus? The second sperm nucleus enters the embryo sac right behind the first. There it unites with the double nucleus lying in the center of the embryo sac. Since the double nucleus is not an egg nucleus, this union does not result in the formation of a fertilized egg cell or zygote. Instead, the final result is a group of food-storing cells called the *endosperm*. The double nucleus is therefore often called the endosperm-forming nucleus. *Exercise 6.*

How does the fertilized egg cell grow into an embryo plant? When it has been fertilized, the egg (zygote) begins a series of divisions. Division occurs again and again until a mass of cells is formed; the process is somewhat like that of cleavage in an animal. However, these cells do not later arrange themselves in the form of a hollow ball or cup; such embryonic stages are found in animals only. But differentiation does occur; some cells are made into ducts, some into wood cells, and so on. Soon the tiny stem, root, and leaf become apparent. Although they are small and all curled up, you can recognize the beginnings of a new or embryo plant. The leaves, of course, are still without color since the embryo is locked up within the embryo sac which lies within the ovule, which in turn is in the ovary of the pistil; no rays of light have yet reached the embryo to enable the green chlorophyll to form. The embryo, though small, is considerably larger than the egg cell from which it grew, because food is delivered to the embryo constantly while it is developing.

Meanwhile the endosperm nucleus has also divided many times and the cells thus formed now contain large amounts of starch and other nutrients. This food material is packed around the growing embryo. In some plants it is absorbed later by the embryo as it develops; in others it is still present after the embryo is completely formed. *Exercises 7, 8.*

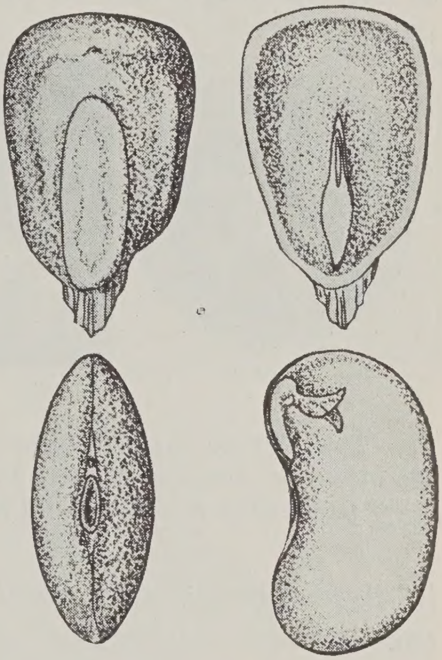
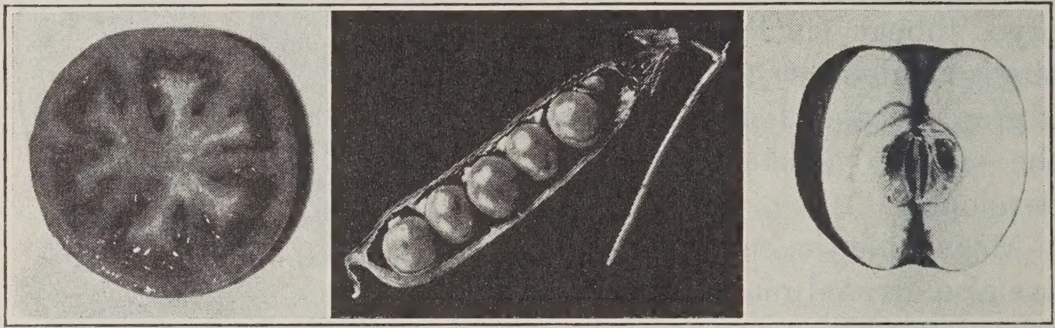


FIG. 293. Seeds of the bean (below). The opened seed shows all parts of the embryo. Kernel of corn above. The section (on the right) shows much endosperm around the embryo.

What other changes occur in the flower while the embryo develops? The development of the embryo after fertilization occupies many days or weeks so that in the meantime the flower petals have dried up and fallen off. A blossom does not last long; it withers, leaving nothing usually but a few shriveled flower parts and the ovary attached to the flower stem. But in the meantime the ovary has begun to grow. This growth continues. After some days, if you cut the ovary open, you will see that the once small ovules are becoming larger too. This is not surprising since the ovule contains the developing embryo. The embryo is growing so much that it would soon burst the wrappings of the ovule did not the ovule grow to keep pace with it. In the end, the ovule becomes large enough to be visible to the naked eye; it may in some instances be an inch across. When full grown it is no longer called an ovule; it is called a *seed.* The seed, or ripened ovule, therefore, always consists of an embryo enclosed in wrappings or seed coats; sometimes there is endosperm present, too.

The enlarged ovary with its enclosed seed or seeds is now known as a *fruit.* It may have grown enormously and changed its appearance completely, for sometimes other parts attach themselves to the ripening ovary so that the fruit becomes fleshy or changes its appearance in some other way. A fruit is not always something that can be eaten by man. Normally, every flower that contains a pistil will produce a fruit of some kind. *Exercise 9.*



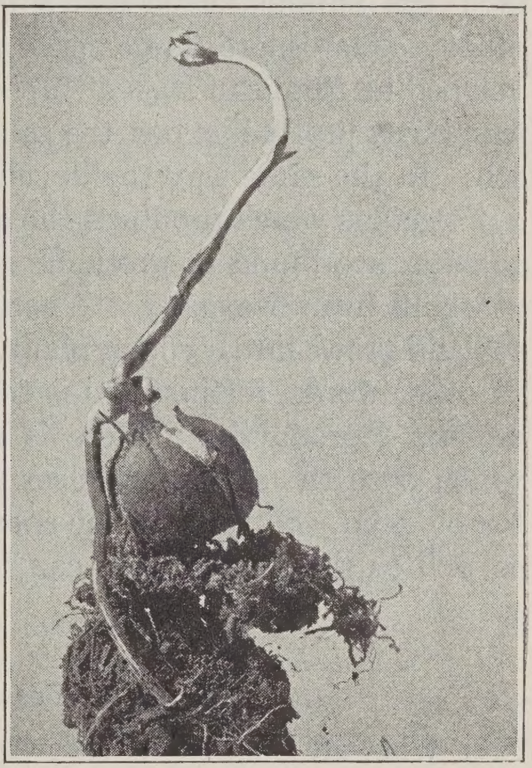
Courtesy Brooklyn Botanic Garden and H. Schneider

FIG. 294. Three ripened ovaries or fruits containing seeds. In the tomato the ovary has become fleshy. In the apple the core is the original ovary and other parts have grown around it.

When is reproduction in a flowering plant finally completed? In this long story of reproduction the embryo was left still locked up in the seed and the seed was still safely inside the fruit. The fruit, or parts of it, may remain on the plant a long time. Eventually, however, the fruit opens up or drops off. If the seeds fall to the ground and have enough warmth and moisture they soon sprout and the embryo quickly develops into a young plant or *seedling.* This growth of the embryo into a plant is called *germination.* Often a seed remains in the frozen ground over the winter months. In the spring, it germinates. It bursts its seed coat and pushes out of the earth. An animal embryo does not rest in this way during a period of unfavorable conditions. *Exercise 10.*

How does the fern reproduce? As you know, ferns do not bear flowers. They produce spores asexually by the process of sporulation. At certain seasons, the spore cases show clearly on the lower surface of the *frond* (leaf). When the spores ripen they fall out of the cases and are scattered on the ground. Protected by their thick walls, they remain inactive for some time; later, if conditions are favorable, they develop.

But, strange as it may seem, a spore does not grow into a new fern plant. Instead, it produces a small heart-shaped green body (called a *prothallus*) which bears no resemblance to the parent plant. The prothallus lies flat on the ground and has tiny hairs that absorb soil water. Since it contains chlorophyll and can make starch it grows, but never grows much larger than a fingernail. After a few weeks, certain of its cells change into sperm, others into egg cells. The sperm, by lashing their tails, swim through the thin film of water on the lower surface of the prothallus (ferns can grow only where there is considerable moisture, at least at certain times), and one sperm fuses with each egg. The fertilized egg cell or zygote then divides many times and its cells go through differentiation. Each fertilized egg becomes a small stem and roots; and in time the characteristic fern leaves (fronds) rise up into the air. With their appearance reproduction is at last completed, for new fern plants like the original fern have been produced.



Courtesy Am. Mus. Nat. Hist.

FIG. 295. This oak seedling has burst open its coats (seed and fruit), in which it rests during the winter. It has been growing on the food stored in the seed.

But the important fact to note is that before the new fern appeared by sexual reproduction a little prothallus plant was produced by asexual reproduction. There must always be an asexual and a sexual reproduction in regular rotation before the fern has formed an individual like itself. This is called an *alternation of generations:* the fern plant produces spores asexually; these grow into a prothallus (not a fern); the prothallus produces gametes, and the fertilized egg cell grows into the new fern plant. *Exercise 11.*

In what ways does the reproduction of a flowering plant resemble that of the fern? While a flowering plant seems to be different from the fern in its reproduction, close study shows that it, too, goes through an alternation of generations. To the botanist the pollen grain is a spore and so is the embryo sac. In fact, the botanist calls one a microspore (small spore) and the other a macrospore (large spore). When the pollen grain has developed he thinks of it as a three-celled prothallus, tiny and colorless, but a prothallus just the same, because it produces the sperm cell. In the same way the developed embryo sac is thought of as a prothallus which produces the egg cell. Here, as in the fern, the gametes are found in prothalli which grow out of spores. These prothalli form asexually. When the sperm cell fertilizes the egg cell and grows into a young plant, sexual reproduction is occurring. In other words, fertilization is tied up in regular rotation with an asexual reproduction; there is an alternation of generations in which both the sexual and asexual stages take place right within the blossom. So tiny are the spores and prothalli that the asexual as well as the sexual stage can be studied only under the microscope.

Exercises

1. What are the parts of a flower? Study a tulip, gladiolus, or some other simple flower in season. Use the description in the text as a guide. Draw one or several diagrams of your flower and label all of the parts.

2. What is the structure of a pollen grain? Rub the ripe anthers of several different flowers on separate slides and examine under the low power. How do the pollen grains differ? What advantage is there in the projections on the surface?

3. How may pollen tubes be made to grow? Shake pollen from ripe anthers into a sugar solution of about 10% (vary the concentration of sugar and use the one that gives best results for the kind of pollen you are using). Set aside and examine after a few hours. Draw the pollen tubes in various stages of development. Stain with iodine solution and look for nuclei. How many do you find?

4. Some flowers are self-pollinated; others are cross-pollinated by wind or insects. Make three columns on your paper and head them self-pollination, insect pollination, wind pollination. Arrange the characteristics listed below in the proper column or columns and wherever possible name a flower which shows that particular characteristic:

1. dry and light pollen
2. stamens shorter than pistils
3. sweet odor
4. bright colors
5. large nectar sacs
6. long feathery stigma
7. corolla in form of long tube
8. large corolla
9. anther and stigma ripening at different times
10. calyx and corolla almost lacking
11. flower growing on long flexible stem
12. flower high up on trees
13. stamens that spring up when touched
14. sticky pollen

Can you name any other characteristics which would fit a flower for one type of pollination?

5. What happens when a pollen grain falls on a ripe stigma? If a tulip blossom is available, transfer some ripe pollen with a toothpick to the stigma of the pistil. (If the stigma is well expanded and hairy it is ready to receive the pollen.) After three or four hours, cut a small piece from the top of the pistil, crush it on a slide, mount it in water and examine it under low power. The thick growth of hairs of the stigma is noticeable. Look for pollen grains among the hairs. Have any pollen grains formed tubes? Look for nuclei. Is the tube open or closed at its end? Why is this necessary? If the pistil had been left undisturbed in which direction would you have found the pollen tubes growing?

6. How does double fertilization take place in flowering plants? If prepared slides are available, examine the embryo sacs under high power. Can you find the eight embryo sac nuclei? Where are they? Are there cell membranes about each? Can you distinguish the egg nucleus and endosperm-forming nucleus from the others? How? Can you find the two sperm nuclei? Is the tube nucleus still visible? Draw the embryo sac and the nuclei exactly as you see them. If fertilization does not seem to have occurred, examine other embryo sacs on the slide. How can you tell that fertilization has been accomplished? If slides are not available, study charts or photomicrographs.

7. What is the structure of the seed? Soak dried lima bean (or kidney bean) seeds overnight. Notice the scar (*hilum*) on the side of the bean. What causes the scar? If you press the bean gently you can see a tiny hole at one end of the scar. This is the *micropyle*, a small opening. What must once have entered through this micropyle? Remove the seed coats and carefully separate the two large, fleshy, leaflike structures. These are the *cotyledons*, or seed leaves. To what are the cotyledons attached? Describe. This is called the *hypocotyl*. Examine the hypocotyl with a magnifying glass. What do you find at one end lying between the cotyledons? It is known as the *plumule.* Into what do hypocotyl and plumule grow if the seed is allowed to sprout? What name could you give to a baby plant such as you have just seen? What did you find protecting the baby plant (which consists of cotyledons, plumule, and hypocotyl)? Stated briefly, of what does a seed consist? Since plumule and hypocotyl will grow into root, stem, and leaves, what might be the function of the fleshy cotyledons? Test the cotyledons for starch and protein. What do you find?

8. What do you learn from the study of the pea pod? Carefully examine the outside of a pea pod close to the stem. What do you find? Where have you seen these parts before? If you have a blossom of the garden or sweet pea take out the pistil. Lay it next to the pea fruit. What resemblances do you find? Open the pod carefully so that the "peas" remain attached. If the pea pod is a fruit what are the "peas"? What were the "peas" when they were young? Does the pod contain any undeveloped seeds? Explain. The region of the fruit to which the seeds are attached is the *placenta.* Why must the ovules (and young seeds) be attached to the ovary? The pea pod illustrates the origin of a fruit. What can you conclude about fruits in general?

9. What happens to the seed under favorable conditions? Line a battery jar with moist blotting paper and place a few fresh or soaked lima beans between the paper and the jar. Keep a record of the development of the seeds from day to day. Which part first bursts through the seed coats? Grow some seeds in moist sawdust. Plant them about an inch below the surface. Which part first appears above ground? How is it kept from being injured as it pushes through the sawdust (soil)?

10. To what extent is a pea or bean seedling dependent on the food stored in its cotyledons? Carefully cut away the cotyledons from several seedlings which have begun to sprout. Give them favorable conditions for growth (moisture and warmth). Leave the cotyledons on several seeds and grow them with the others. Observe closely and record. What conclusions do you draw? Cut away one cotyledon and repeat the experiment. Does this make you more sure of your conclusions or not? Why?

11. How does the fern perform asexual reproduction? Using a hand lens, examine the lower side of a fern frond (leaf) which has formed spores. You can see masses of spore cases; each case is too small to be seen. How are the cases protected? Mount some of this material and study under the low power. Describe. Do you see spores? About how many spores would fit into one case? Why do you say that these spores have been formed asexually? Why has reproduction not been completed when these spores develop into a little prothallus?

Problems for Classroom Discussion

1. Can you explain why animal reproduction was understood before plant production?

2. Do you think the "ovary" of a plant is well named? Give your reasons.

3. Why can an ovule not be considered a gamete?

4. When clover was first introduced in Australia, it almost died off. After the importation of bumblebees, the clover flourished. Why?

5. Which of the nuclei in the pollen tube do you consider most important? Why?

6. If the pollen grain of a corn plant lands on the stigma of a wheat flower, it does not grow. Can you suggest an explanation?

7. Can a flower without a pistil produce seeds? Explain.

8. What harm is done by a severe frost which occurs while peach trees are blooming?

9. How are the apple and the string bean alike?

10. List fruits which are commonly called vegetables.

11. Which part of a seed sprouts first? Why is this of advantage to the seedling?

12. Which part of the fern cycle is more easily observed, sexual reproduction or asexual reproduction?

13. *Summary.* Write a story telling how a flower changes into a fruit and a seed develops into a new plant. Make it brief but be sure to include the important steps. This story will answer the problem question. More difficult and more technical is the explanation of alternation of generations in fern and flowering plants. Can you explain that?

Activities for the Junior Biologist

1. If you have patience you can raise fern prothalli from spores. Sprinkle spores of the Christmas fern on moist sterile soil (in a dish) and cover with a plate. Watch for the tiny green structures; it will take several weeks.

2. Make an exhibit of flowers or of a series of charts to show how flowers are constructed to prevent self-pollination or to secure wind or insect pollination.

3. Find out how flowers are pollinated by hand for experimental purposes and demonstrate the method to your class. Include in your talk the reasons for this type of pollination.

4. Devise and perform experiments to discover whether moisture and air are needed by germinating seeds. Report.

5. Does light affect the germination of seeds? Devise an experiment.

6. Report on the pollination of the Yucca flower by the Pronuba moth.

7. Chemicals of various kinds are used nowadays to speed up the germination of seeds. Look this subject up and report to the class. Consult files of the *Science News Letter*.

8. Do seeds lose their power of germination with age? If there are any old seeds in the laboratory, such as old ears of corn, mounted heads of wheat or other grains, of which someone can tell you the approximate age, soak them and lay them between moist blotters which have been sterilized by heating. Keep moist. Report.

9. Germinate the seeds of apple, orange, lemon, avocado, and other fruits. Study their germination. How does it differ from the germination of bean seeds? Plant some of the seedlings.

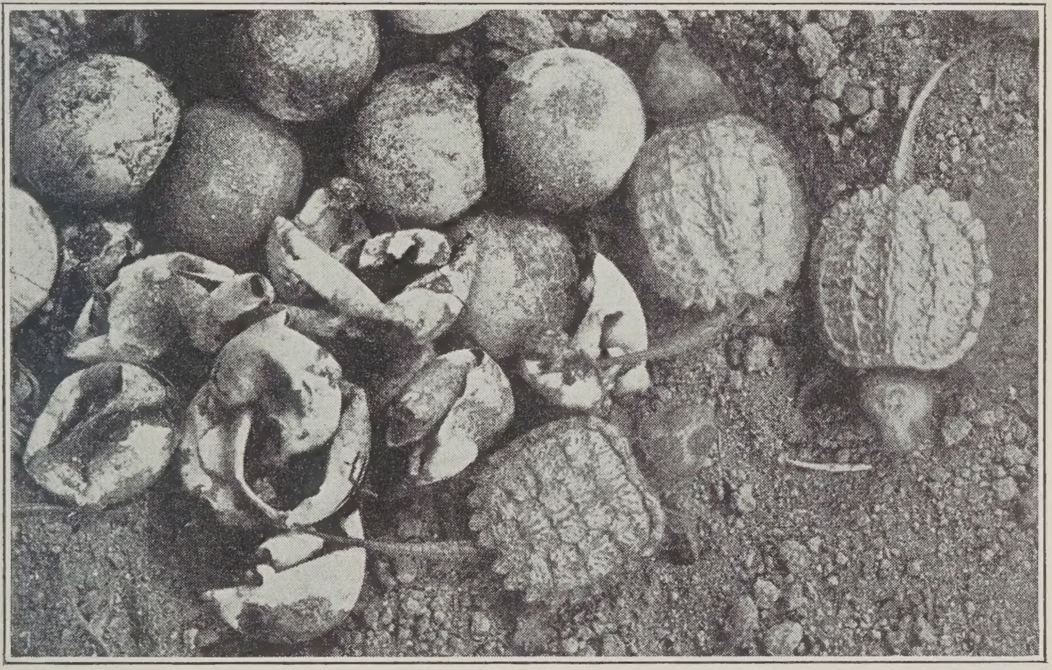
Problem 5. On What Factors Does Successful Reproduction Depend?

What is meant by successful reproduction? Unlike the other processes which go on in the organism — food-getting, digestion, respiration, and so on — reproduction is of no value to the individual. Its only value is to produce new individuals which keep the species from dying out. In order that a species may maintain itself every two individuals must be replaced by two offspring that grow to maturity and in their turn produce offspring. When this does not occur, the species steadily decreases in numbers until, finally, there are no more individuals left and the species becomes extinct (dies out).

Most kinds of plants and animals must produce many more than two children to maintain the species, because few of their offspring survive until they are adults. And while there are great differences in the number of offspring produced by the various kinds of animals and plants, every species that survives replaces each adult with at least one new individual. This is said to be successful reproduction.

What dangers beset the young of animals? If life on this planet were as simple as it seems to the casual observer the young would survive as readily as the adult. But life is not simple for any organism. Throughout life every animal must struggle for existence. It must struggle to escape or overcome its living enemies. It must meet unfavorable conditions of temperature. Scarcity of food is a common occurrence. And there is danger of drought and drowning or danger from wind and tides. There are countless possibilities of destruction which at first thought may not occur to you.

Now the egg, the embryo, and the young animal are much more likely to be killed than is the adult. They are more sensitive to heat and cold; and, being small in size, they are less able to resist strong winds, heavy rains, or strong water currents. Since they are undeveloped they may be slow in locomotion; they may lack nerve connections and be unable to receive stimuli promptly and to make correct responses. If there were no struggle for existence the young would be able to grow up despite their weaknesses; actually, only some of them succeed in remaining alive. In some cases comparatively few, in other cases, large numbers die.



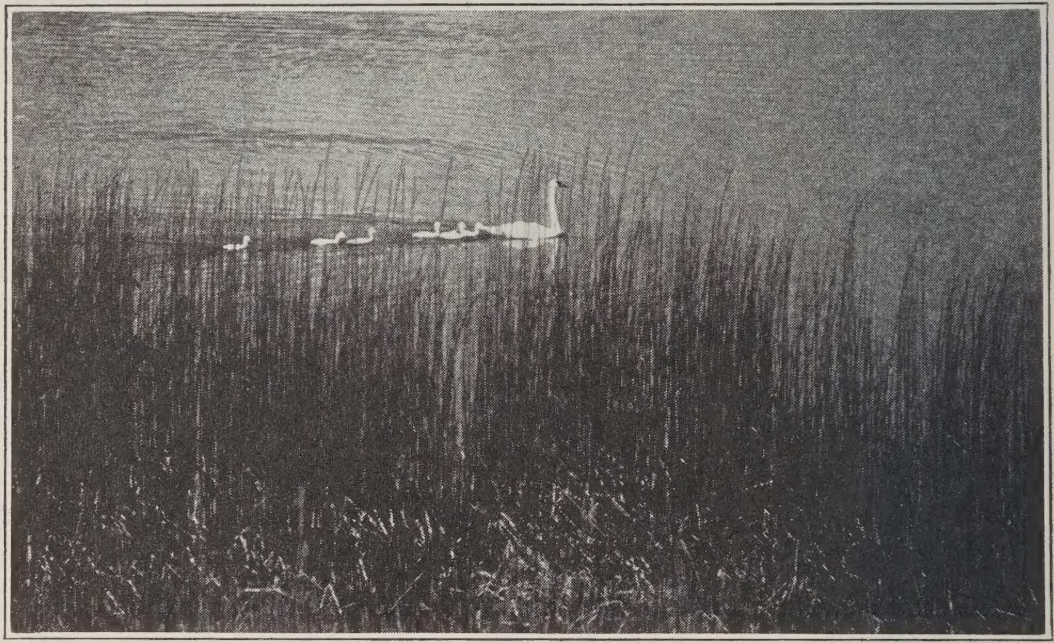
Courtesy American Museum of Natural History

FIG. 296. Snapping turtles hatching from the eggs.

How do some animals lessen the dangers that beset the offspring in the earliest stages? When the fish deposits its eggs or sperm in the water, often in the waters of the open ocean, it leaves them at the mercy of the elements and many animal enemies. They are lost in countless numbers. In land animals, as well as in some aquatic forms, as you know, this loss is prevented because the egg is fertilized while it is within the body of the female.

The developing embryo, too, may receive protection. You have read how membranes and shell are wrapped about the bird's egg before it is laid. Among many reptiles the egg has a tough, leathery covering. Some snakes, however, like the mammals, give the embryo even better protection; they bear the young alive.

In the fish and frog, where fertilization is usually external, there cannot be much of a covering over the egg, or the sperm would not succeed in entering. The eggs of the frog, however, are coated with a jellylike material which swells in the water immediately after fertilization; this keeps the eggs together in a large mass.



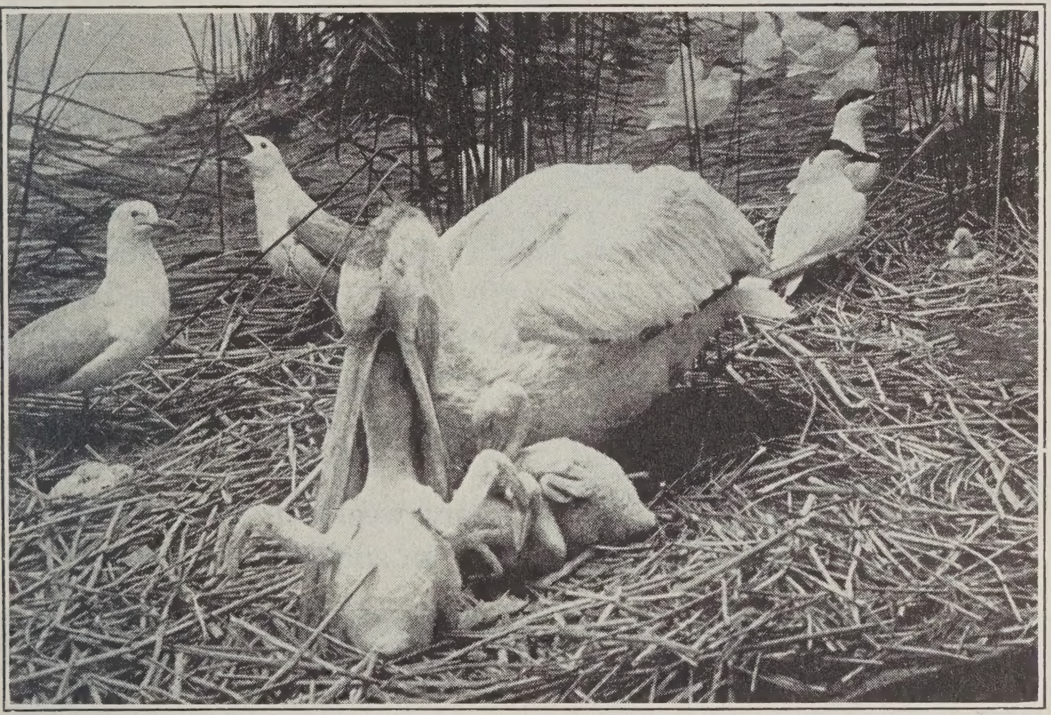
Courtesy National Park Service

FIG. 297. Trumpeter swans. The young remain close to the parent bird.

What provision do birds make for their young after the egg is hatched? Care and responsibility do not end when the bird hatches from the egg. It is true that baby chickens, ducks, turkeys, gulls, and the young of some other birds need relatively little attention. They leave the egg fully equipped to go out with the mother in search of food. They are completely covered with downy feathers, their muscles are well developed, their sense organs perfected. They can walk, peck, and feed themselves. But when danger threatens they scurry back to hide under their mother's wings.

The young of other birds, such as the songbirds and pigeons, are hatched in so immature a state that the parents are obliged to turn all their energies to rearing them. The newly hatched sparrow is naked, its eyes are closed, and the muscles of its wings and legs take days to develop. But it has an enormous appetite and a gaping bill. The parent bird makes hundreds of excursions every day in search of food to feed four or five such hungry mouths.

After the young develop they must learn to fly. The parents often help the young to make the first attempt by pushing them out of the nest. But growth and development are slow. Thus there arises a type of family life among birds in which, usually, both parents play an equal part. Where there is family life the number of offspring is small. Some birds, however, increase this number somewhat by having two broods in a summer.



Courtesy American Museum of Natural History

FIG. 298. Pelican feeding its young. In what respects is the young bird undeveloped? Compare it with the parent bird.

What provision do mammals make for the young after birth? Kangaroo babies are born so undeveloped that the mother must immediately put them into the pouch specially formed for giving the young warmth, protection, and a constant supply of food. In only a few kinds of mammals are the young born in so immature a state. But in many species, such as dogs, cats, mice, guinea pigs, and rabbits, the young are born blind and largely helpless. The human baby has its eyes open when it is born but in other respects it is even more helpless. On the other hand, the babies of grazing animals are much more independent. They are able to stand and even to walk awkwardly and are well protected with a coat of hair. But all mammals are dependent in infancy on the milk secreted by glands in the mother's body. For this reason, the mammals also have developed some form of family life. And in all mammals, except those that have several litters within the year, the number of offspring is relatively small.

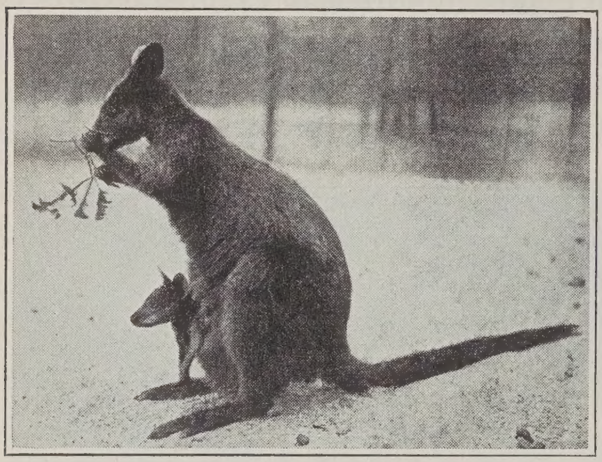

Courtesy N. Y. Zoological Park

FIG. 299. The Wallaby is one kind of kangaroo.

Family life may continue for many weeks or even years, as among elephants and human beings. In such cases parental care means much more than supplying food and hiding the offspring. The young are given an opportunity to learn the ways of life. When the lion drags wounded prey to its lair the cub learns to tear the flesh. To what extent it watches and imitates its parents

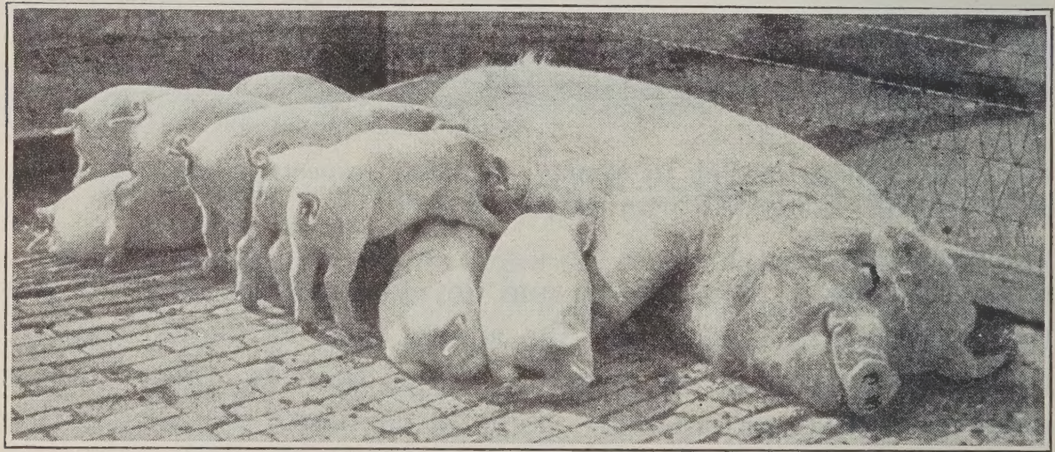
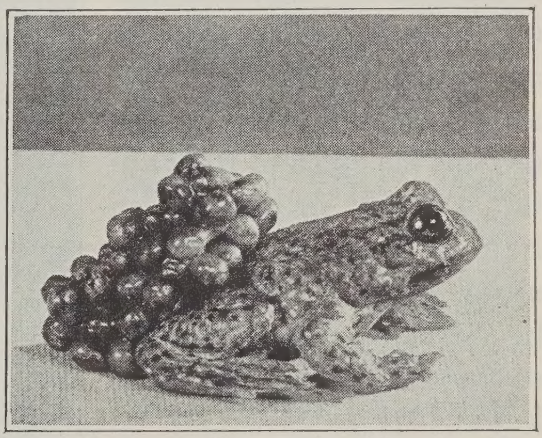

Courtesy North Dakota Agricultural College

FIG. 300. Feeding a large family.

is not known but at least it practices the use of claws and teeth. Among apes and especially among human beings, as you read in the last unit, there is much learning; family life is then prolonged for many years.

What cases of family life are found among the social insects? The social insects, certain of the ants, bees, wasps, and termites, have a so-called family life, too. Some species even live in communities which consist of more than one family. Among the ants a single female, known as the *queen*, after she has received the sperm within her body, settles under ground or in some other protected spot. Some time later eggs are laid and the larvae are tended and fed by the queen mother. They soon develop into worker ants that take upon themselves the various duties within the home. (See Chapter VI, Part 1.) The queen lays more and more eggs. Some in time develop into winged forms, females with ovaries and males with spermaries. They assume no responsibilities and after living in the nest for a while these young females and males, some bright warm day, fly off and mate. Each young queen then starts her own home; rarely do queens return to their former nest to lay their eggs.

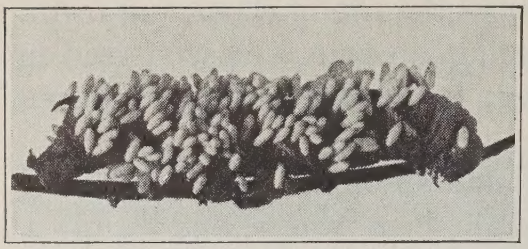
Most insect parents die within a few hours or at most a few weeks after the eggs are fertilized and laid, but the social insects are much longer-lived. Many worker ants live for at least three years, while the queen may reach an age five times as great. It is because of this fact that family life becomes possible. In the higher animals, too, a highly developed family life is found among those that live long.



Courtesy Am. Mus. Nat. Hist.

FIG. 301. The male midwife toad carries the eggs about with him until they hatch into tadpoles.

To what extent do other animals take care of their young? Most of the invertebrates and the fishes and the amphibia among the vertebrates take little care of their eggs and young. However, there are exceptions. The female crayfish may carry the fertilized eggs about with her suspended from the abdomen. And



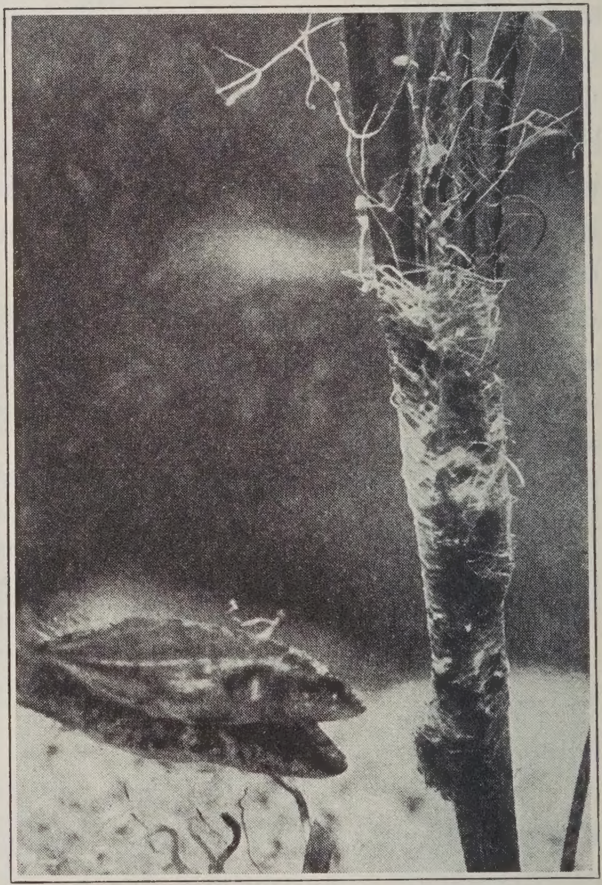
Courtesy Am. Mus. Nat. Hist.

FIG. 302. Wasp cocoons attached to a caterpillar.

some insects show remarkable instincts for protecting their young. Eggs are frequently laid where they will escape observation. The grasshopper carefully places its eggs in the ground, well protected against many enemies and against the cold. Certain flies find some kind of decaying material in which to deposit their eggs; when they hatch, the young find the food that suits them best. The ichneumon fly starts her brood in the body of that particular caterpillar which will later serve as the choicest morsel for her young.

The male of one kind of fish has an intimate method of caring for his family; he carries the developing eggs and the young about in his mouth. Even after they are fairly sizable fish they keep returning to his mouth in an emergency. How often he yields to the temptation of hunger no one but he knows!

What special provision do plants make for their embryos and young? Among flowering plants the embryo is particularly well guarded. When the embryo is fully formed it is given a good send-off, and this is important, because plants find no safety in numbers. Animals often live in herds or flocks for protection. But for plants, which lack the power of locomotion, it



Courtesy N. Y. Aquarium

FIG. 303. The nest of the stickleback is made of water weeds glued together with a sticky substance secreted by glands in the body of the male. He guards the eggs that the female places in the nest.

is an advantage to be separated as far as possible from the rest of the family. If members of the same species remain too close to one another there is too great competition for food and light. Fruits or seeds are adapted in countless ways for wide dispersal. The seed may be fitted with wings or tufts of hair which keep it floating in the breeze. It may have spines or hooks which cling to the fur of some passing animal and become loosened later when it is far from the parent plant. The seed may remain within the fruit, which becomes fleshy and brightly colored to tempt some animal to carry it away. And there are many other interesting adaptations for *seed dispersal. Exercise 1.*

Each embryo, therefore, is sent off to journey far from home, but it leaves securely wrapped in its seed coats. The embryo can rest while the earth is cold and dry; yet with warmth and moisture its cells become active. It is well supplied with food on which it can draw until the leaves are making starch and sugar. It makes no difference in the process of germination whether food is stored as endosperm or in the cotyledons. Either makes it possible for the baby plant to survive in its first struggles for existence.

How do plants and animals that take little or no care of the young succeed in preserving the race? Some animals take special care of their offspring. Many eggs and embryos and young are fitted in one or several ways to survive the dangers to which they are

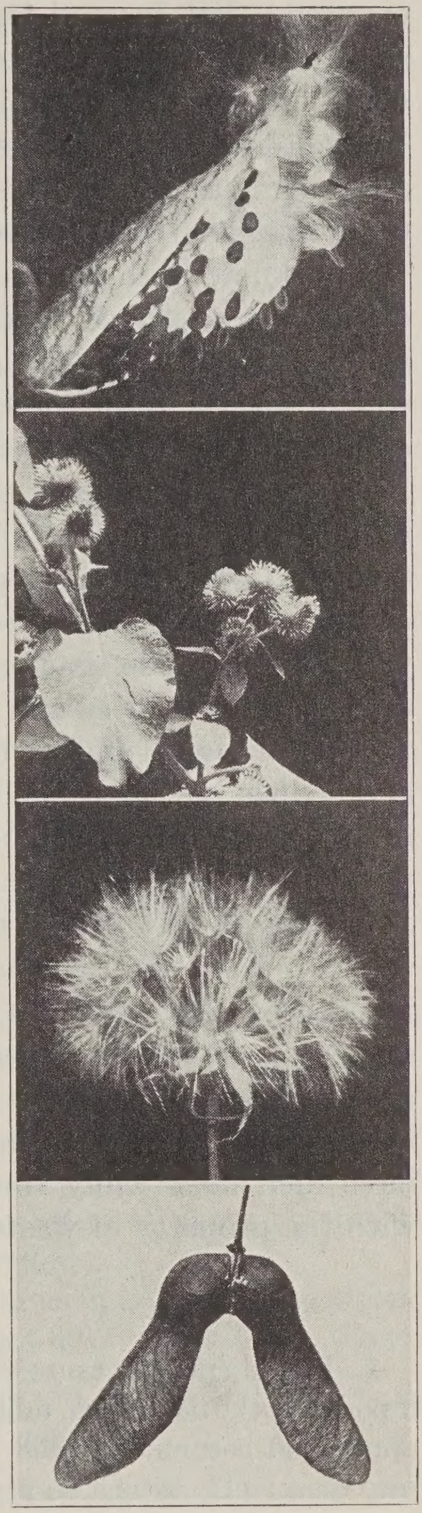


Fig. 304. Fruits and seeds of milkweed (top), burdock, dandelion, maple. (*Photos Am. Mus. Nat. Hist.; Schneider & Schwartz; Brooklyn Bot. Gar.*)

exposed. Yet by and large, the possibilities for destruction are so varied and so numerous that most species would quickly become extinct did they not meet the problem in another way. They do it by producing such enormous numbers of offspring that a few are sure, somehow, somewhere, to escape enemies and all the other dangers that threaten them.

You know that each fern leaf may have countless spore cases on its lower surface. Each case is filled with many still tinier spores. Each spore can grow into a small green structure from which several fern plants can grow. The number of possible children of the original fern plant is too great to be counted.

Among some animals the same is true. A female cod, for example, may lay 8,000,000 eggs every season. If only two of that 8,000,000 grow up and reproduce, the race is provided for. Since cod at the present time seem not to be increasing in our waters you may conclude that only two of the 8,000,000 can be counted on to reach maturity and become parents.

Not all plants and animals have as many children as the fern and codfish, yet many do and almost all reproduce at an astounding rate. You may ask how it is that such prolific (plentiful) reproduction happens to be found in the fish and other organisms. Some people say that "mother nature" provides for all living things. But "mother nature" is just an expression to cover ignorance. The biologist thinks he has a better answer to the question. It is this: Should the cod lack its ability to produce so many eggs and sperm the species would die out. No doubt many kinds of fish that could not keep up in the race of reproduction have died out. Only those survived that happened to develop with the property of wasteful reproduction.

Exercise

1. How do plants ensure the widespread dispersal of their seeds? Study, if possible, the dandelion, milkweed, linden, cocklebur, witch hazel, poppy, apple, and coconut for seed dispersal. How is each specimen fitted for seed dispersal? Which do you think are best fitted? Can you give other examples of seed dispersal that you have noted?

Problems for Classroom Discussion

1. Explain how the parent bird helps the offspring by sitting on the eggs.

2. Why are reptile eggs helped more by being laid in the sand than by having the parent sit on them?

3. When eggs have heavy coverings what do you know about the type of fertilization of that animal?

4. Considering the feeding habits of the adult, why is it important that the young of cows, horses, and similar animals should be comparatively able to take care of themselves when they are born?

5. An elephant lives one hundred years and matures slowly. Does that have any bearing on parental care?

6. Can you show a possible connection between the amount of parental care and the complexity of the brain?

7. How does the family life of a social insect, like the ant, differ from the family life of a bird?

8. Is it true that the more complex the animal, the longer the period of helplessness in babyhood? Cite examples to support your answer.

9. Compare "parental care" in plants and animals. Is one more effective than the other? Which is more complex?

10. Why is it that so few water-living forms have developed with instincts for guarding the eggs and young?

11. Why is burdock more likely to grow scattered along a roadside than in thick clumps in a field?

12. Why do dandelions so often dot your lawn?

13. Seeds and fruits are fitted by structure for being carried by various agents. Name those agents and name a seed (or fruit) carried by each.

14. The starfish lives where the tide goes in and out; the frog lays its eggs along the banks of a pond; the codfish lays its eggs in the ocean. What would you expect to be true of the number of eggs laid by each?

15. *Summary.* Summarize the problem by listing the factors on which successful reproduction depends. Give examples.

16. *Unit Summary.* If you have made a summary of each problem you can now put those together and discuss fully "How living things reproduce."

Activities for the Junior Biologist

1. Look up the death rate of children and young people in your city or state. On the average, how many children must be born into each family if the population is to maintain itself? What is the actual average number of children per family in your city or state?

2. If you are interested in photography, take a series of pictures to illustrate parental care in some animal. A bird at its nest is one of the most difficult; ants scurrying around to save eggs, larvae, and pupae after a stone has been upturned, one of the easiest.

3. Build an ants' nest (as described in many insect books or the Turtox leaflet). Study their home life and report. Get some ants, being sure to include the larger queen. Feed on sugar water. Study for some weeks and report.

4. If you like to write, tell the story of the life of a young bird from the time it pecks its way out of the shell to the day that it leaves the nest. Why not write in the first person?

5. Make a collection of fruits and seeds to illustrate the many methods of seed dispersal in plants. Keep them in Riker mounts.

Good Books to Read

Coulter, J. M., *Plant Life and Plant Uses.* American Book Co.
De Kruif, P. H., *Microbe Hunters.* Harcourt, Brace.
Gager, C. S., *The Plant World.* University Society.
Goldschmidt, R. B., *Ascaris; the Biologist's Story of Life.* Prentice-Hall.
Hegner, R. W., *College Zoology.* Macmillan.
Locy, W. A., *Biology and Its Makers.* Holt.
Lovell, J. H., *The Flower and the Bee.* Constable.
Shipley, A. E., *Life.* Macmillan.
Singer, C., *Story of Living Things.* Harpers.
Sinnott, E. W., *Botany.* McGraw-Hill.
Skene, M., *The Biology of Flowering Plants.* Macmillan.
Waddington, C. H., *How Animals Develop.* Norton.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.
Williamson, H., *Salar the Salmon.* Little, Brown.

UNIT VIII. HOW ARE PLANTS AND ANIMALS FITTED TO SURVIVE?

Problems

1. How Do Plants and Animals Meet the Various Physical Conditions of Their Environments?
2. How Do Organisms Injure One Another?
3. What Means of Defense Do Plants and Animals Use against Their Foes?

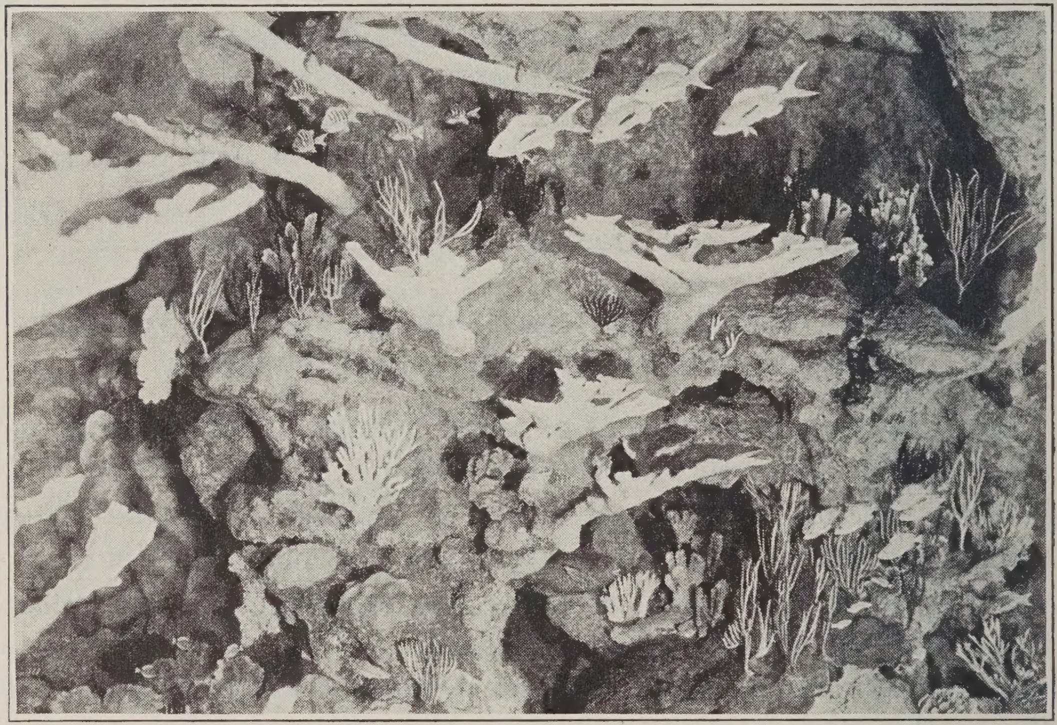
Problem 1. How Do Plants and Animals Meet the Various Physical Conditions of Their Environments?

How does an environment of water compare with an environment of air? Because you are air-breathing and live on land, and because for that reason you are most familiar with land-living forms, you tend to think of land as the "normal" environment, water as abnormal. You think of special ways in which water forms must be fitted to their strange home. As a matter of fact, water is the most usual environment, for almost three quarters of the earth's surface is covered by water. It is land-living forms that have been obliged to fit themselves in one way or another to an environment of air.

Living conditions in the water are simpler than those on land. Water is one of the substances necessary to all living things. Whether living on land or in water all organisms must have water, for the protoplasm of which they are composed is largely water. And in the more complex, many-celled organisms, both plant and animal, watery mixtures, sap or blood, are necessary for carrying materials around the body. The water-living form has all the water it needs right at hand.

And consider the factor of temperature. Whereas, on land, in the temperate zones, the temperature changes regularly and quickly from midday warmth to the coolness of the night, in the sea, the temperature remains almost uniform during the hottest part of the day and the coldest hours of the night. From winter season to summer, too, there is far less variation in the temperature of the water. Water at the poles and water at the equator show smaller differences in temperature than does the air that covers the land in these regions.

In water, the effect of gravity is comparatively unimportant; water holds up the animal. On the other hand, land-living forms are obliged to remain on the surface of the earth. While some have become fitted for traveling through the air, they cannot remain there indefinitely; gravity soon brings them back to the ground.

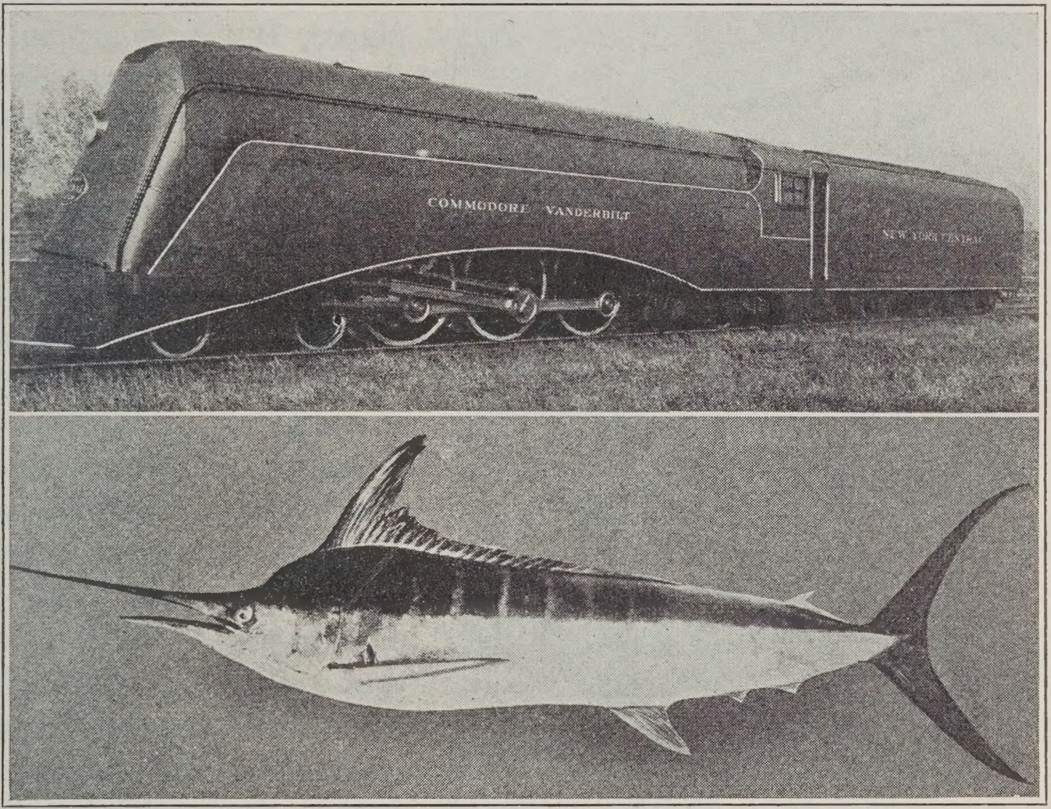


Courtesy American Museum of Natural History

Fig. 305. An undersea coral "garden." In warm shallow water life is abundant. The plant-like forms are really animals (coral).

So far as the obtaining of air goes, land-living organisms may have a real advantage. Air, it is true, is dissolved in water. In a running brook or along the shore where water is tossed up in spray or waves it is well *aerated* (a′er-ate-ed — mixed with air). But the still water in a pond or water in the deeper layers of the sea may contain little air; not enough to keep alive a large number of living things.

What general differences exist between water-living and land-living forms? Land-living plants and animals that grow to any considerable size need far more supporting tissue than do water forms, for the water buoys up (keeps floating) soft bodies which would collapse in air. Bones and exoskeletons in animals, woody and supporting tissues in plants, are sometimes poorly developed in organisms that spend their lives in water. On the other hand, because it offers support, water also offers more resistance to the passage of a body in motion than does air; you have discovered this if you have ever tried to walk through water. Thus, rapid locomotion on land is possible in an organism with any shape, but only streamlined animals can move with great speed through water. Some water-living forms also have scales which overlap from the head to the tail so that friction is lessened; and some, like fish and amphibia, secrete a slime which makes them as slippery as though they had been greased. *Exercise 1.*



Courtesy N. Y. Central R.R.; Amer. Mus. Nat. Hist.

FIG. 306. How are the shapes of the locomotive and the fish alike? Of what advantage is such a shape? Which has more resistance to overcome?

Many water-living forms have another problem, that of rising or sinking, and remaining afloat while at rest. Many fish have an air bladder which can become larger or smaller, thus enabling the fish to rest at different levels in the water. *Exercise 2.*

You already know that there is a difference in the breathing organs of land- and water-living animals. Lungs or breathing tubes cannot be used under water; gills take their place. But among plants there are differences too. While land plants are provided with stomata and lenticels for the easy inward and outward movement of gases, water plants lack these structures. The hard waxy coverings which prevent undue evaporation in the land plant are not necessary. Water plants are usually protected by soft membranes. These have thin-walled cells, through which gases are constantly passing by osmosis, and water plants frequently have in their tissues abnormally large air spaces which act as reservoirs and supply the internal cells with air.

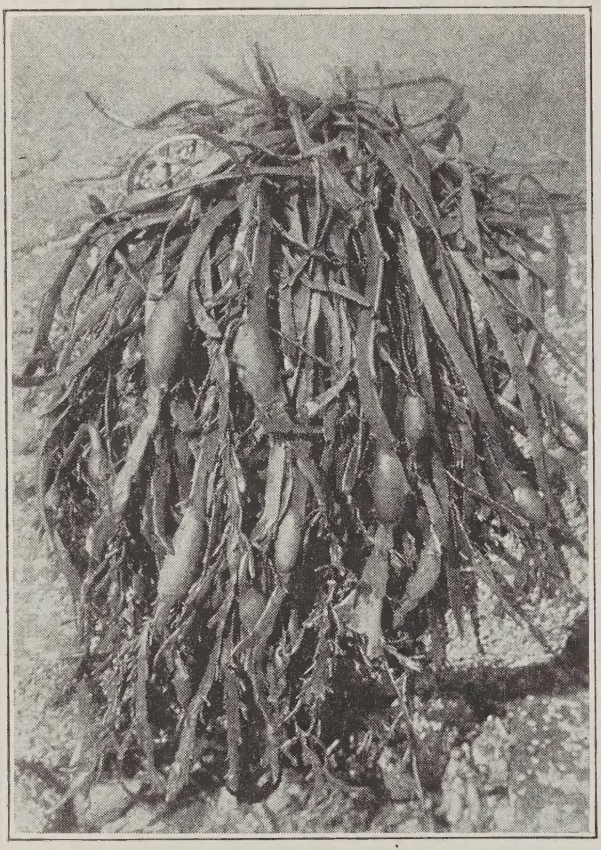


Photo by L. W. Brownell

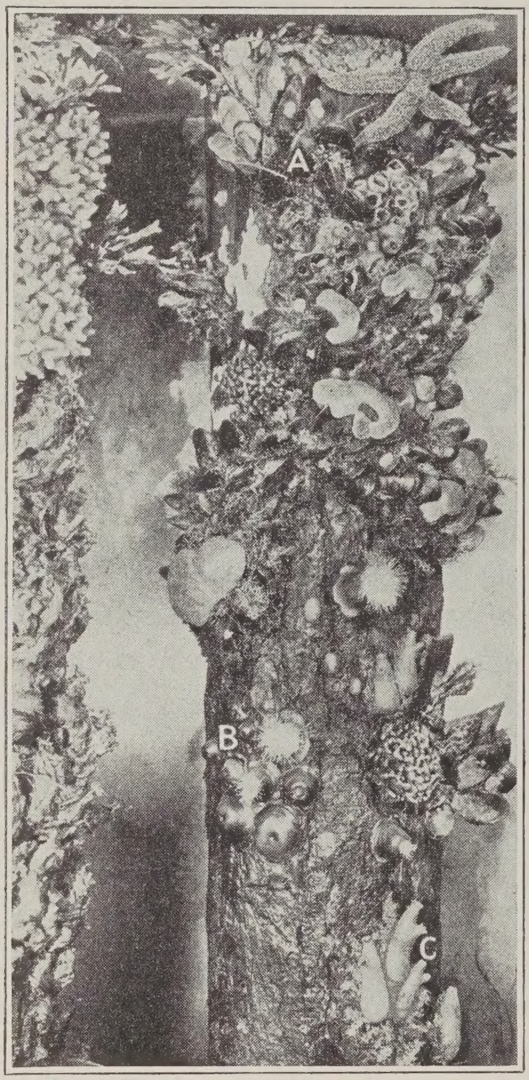
FIG. 307. The rockweed, a brown seaweed common on our coasts, has many little air bladders. These are blown up so that the ribbons float near the surface.

Even a hasty study of plants and animals will show you other structures which adapt (fit) them in a general way to a life in water or a life on land. Often animals and plants show more special adaptations to a particular environment.

What enables organisms to survive in the restless waters of the shore? If you live on the great plains or in the mountain ranges and have never seen an ocean, you do not know the thrill of the wide sandy beach and rocky shore, the flat, far-spreading waters of the ocean fading gray into the sky on the distant horizon, and the unceasing rhythmic thunder of the beating surf. Here among the cracks and rifts, on rocky ledges, in rushing channels, and in still pools, innumerable organisms find their homes. The sandy beaches sought by bathers are less favorable for studying ocean life; it is the rocky coast that provides a truer picture of this difficult environment, half water, half land.

Here, in the region that lies between high tide and low, are vast numbers of living things, both plant and animal, successfully facing conditions which would destroy creatures less well fitted. This is the region from which the life-giving water is absent twice each day as the tide goes out. Twice, too, this strip of shore is torn and sucked and beaten by the incoming waters. It is a region of constant change, but the same conditions, drying up and pounding waves, occur again and again in regular order. Protection against the terrific beat of the inrushing tide is obtained in various ways. Seaweeds are often ribbonlike; these streamers cannot be torn by the pounding and the tossing. Many organisms are toughly built; the brown seaweeds, tough and gelatinous, can hardly be torn by the severest storm. The sea anemones (a-nem′o-nees) have a firm outer membrane. Some of the other animals have hard shells. And these protective devices serve another purpose as well; they make it possible for the animal to shut up shop while the tide is out. The mussels and barnacles on the rocks pull down the shutters and rest while there is no opportunity to obtain food or oxygen. The clams and razor shells draw in their siphons; the sea anemones in tiny pools pull in their spreading, waving tentacles and contract into solid little mounds; the corals slide into their cups. Tube worms cover their burrows. Periwinkles plug up their shells with horny trap doors; the flattened crabs crowd into niches where some water remains caught. All the water-dwelling animals of this most exciting of environments lie low and wait until the next tide enables them to begin their vigorous hunt for food again.

But this region between high and low tides has advantages for the organisms that can resist the pounding and the constant changes. The water is well aerated, containing large quantities of oxygen, and food particles are always being swept in and out by the rushing tide; animals live in plenty. Plants, too, profit by the aerated water: oxygen for breathing and carbon dioxide so necessary for photosynthesis are abundant. And the water is shallow, so that sunlight can filter through. For this reason, each crack and ledge and rocky pool is teeming with living things of many different species. *Exercise 3.*

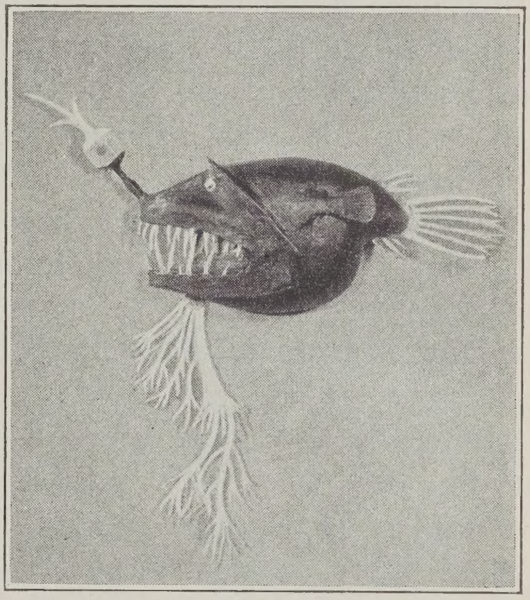


Courtesy Am. Mus. Nat. Hist.

Fig. 308. The museum shows the organisms living on a wharf pile. Which do you recognize? Can you find some anemones that have contracted? (*B*). How are the mussels (*A*) protected against low tide? The sea squirts (*C*) have a tough skin that prevents evaporation.

How are animals fitted to live in the lowest depths of the sea? The sea is not of the same depth all over; here it is shallow, there, profoundly deep. The ocean floor in some regions rises up in towering mountain ranges rivaling the Himalayas. Deep valleys lie between, and plains and vast plateaus. Off Puerto Rico and near the Philippines the ocean floor is sunk more than five miles below the surface of the sea. The lowest depths of the ocean have not even been reached by man's instruments. Perhaps no life exists on such ocean floors; certainly man cannot bring it up if it is there. But he has invented traps and nets of special kinds which make it possible to capture the animals of the lesser depths. With the aid of pressure-measuring devices and dredges, man has learned something of the life in ocean waters down to a depth of at least 20,000 feet. Furthermore, he has learned to take ooze from the ocean floor, the ooze which is composed of the remains of countless living things that died and sank slowly to the bottom. This, too, has taught him a little about life in the deeps.

If you sank slowly downward toward the ocean floor you would find an abundance of life in the surface waters and the waters just below. When fifty fathoms down (one hundred yards) you would note that the seaweeds were growing scarce. Light rays still penetrate but here the days are short, twilight comes early, and the nights are long. A little farther down plant life is lost and animals are of a different kind. The lovely blues and greens so characteristic of surface forms are rare; more dusky forms appear. The octopus writhing for its prey in the semi-darkness is red. Crustacea, worms, and other forms are also red or purplish black. The deep-sea jellyfish are not crystal clear like those in shallow waters. The fish are black or brown. The darkness of the water grows intense. Below, there is a never-ending blackness, save for the dim pale blue and yellow lights that now and then flash faintly through the dark. Light-giving organs are common in deep-sea fish and invertebrates. They can do little to light up the inky blackness of the ocean depths but it is possible that they may help to attract prey or other members of the same species when mating time occurs.



Courtesy Am. Mus. Nat. Hist.

FIG. 309. The oceanic angler fish has a headlight and a beard which may be lighted up in its deep-sea haunts. How is the mouth fitted for catching prey?

And in the deeper waters all is still. An occasional fish darts by, but animal life is scarce where plants cannot grow. The water is almost motionless; there are no waves, only the gentle currents of the deep ocean. The living things of the depths need no protection against battering but they must be fitted to live under enormous pressures. While you must sustain a pressure of fifteen pounds to the square inch they need to bear a pressure of five tons per square inch. This does not mean that deep-sea animals must be constructed like armored tanks; nor are they squeezed by the great pressure as you would be if you went down. They are fitted to the depths because the pressures in their cells and blood streams are equal to the pressures outside of them.

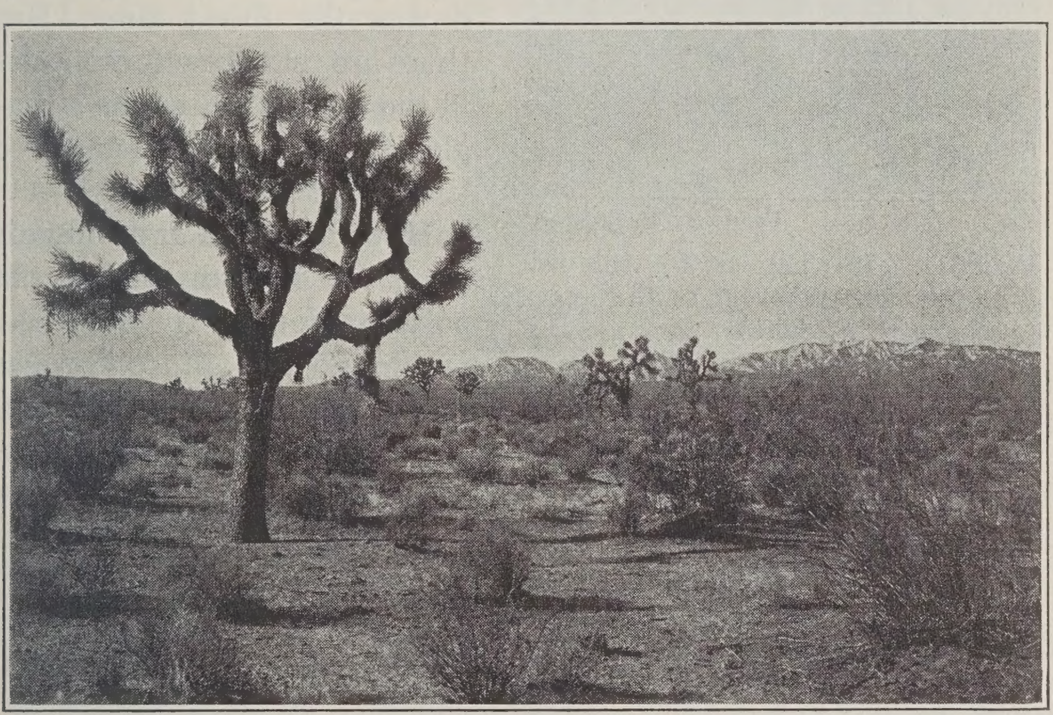
Deep-sea animals are adapted to their strange environment in other ways. In some forms the eyes are missing or almost gone; while others have eyes enormously enlarged. Organs of touch are generally well developed. Most of the fish of the deeper layers have large mouths with vicious-looking, long, sharp teeth, and they have stomachs that can stretch extraordinarily. Their food comes rarely and in large masses, for they eat other fish or the larger bodies that sink down from above. Only large forms drop so far, for the small forms fall slowly and are devoured by the inhabitants of the upper layers of the sea.

Life in the ocean depths is hard. Only relatively few forms have become fit to meet the unfavorable conditions of this strange environment.

How are organisms adapted to inhabit the desert? Not all deserts are places composed entirely of sand; nor are they uninhabited by living creatures. Some, it is true, like large parts of the Sahara, have little vegetation of any kind, but some of the deserts of our western states have a comparatively large *flora* (plant life of a region) and *fauna* (animal life). Mineral food is present in some deserts and when water comes to dissolve it the ground may be fertile. But rain falls only at long intervals so that water is scarce. The lack of rain is serious in itself, but dryness brings with it another unfavorable condition for the plant. It leads to great changes in temperature, intense heat while the sun shines and unusually low temperature at night. Most plants are unable to survive these conditions; only a few species have become fitted to meet the severe environment.

Desert plants usually stand far apart. They have developed large root systems spreading wide to catch the little water that may fall. The plants must be able not only to absorb water quickly but also to hold securely what they get. Thus they often look stunted, gray in color and only half alive. They are tough and woody, harsh to the touch, with hard waxy coverings which prevent evaporation. In some, the stems may be wide and fleshy and serve as large water storage tanks, which supply water slowly to the parts which make food. The leaves are almost always much reduced in size and often take the form of spines. This serves a double purpose; it decreases transpiration and guards the plant from attack by animals. The desert plant which absorbs water from the soil and which is unprotected against the hungry, thirsty animal will soon become extinct.

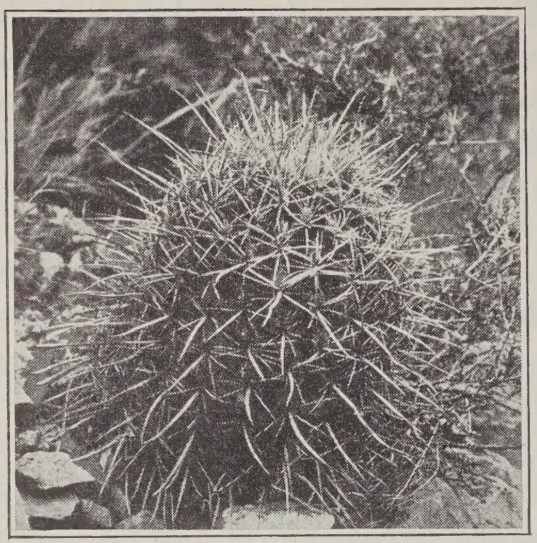
In the deserts which have a brief rainy season every year each plant grows, bears flowers, and produces seed within the short time that water can be had. The vegetation looks fresh and green but not for long. Soon after the rain has ceased the seeds fall, stems shrivel and die, and all is once more brown and gray.



Courtesy U. S. Dept. Interior, Photo by G. A. Grant

FIG. 310. A scene in a California desert. The large Joshua tree is one of many plants growing here. Why is this called a desert?

The animals of the desert are largely reptiles which can stand the high temperatures and the lack of water. The few mammals and birds which have become adapted to desert life frequently live in holes and emerge only after dark to search for food. Some, like the kangaroo-rat, gather large quantities of food and store it; there are long seasons when food is very scarce. Amphibia, of course, are rare since they need water in their early stages and since their thin skin offers little protection against loss of moisture.

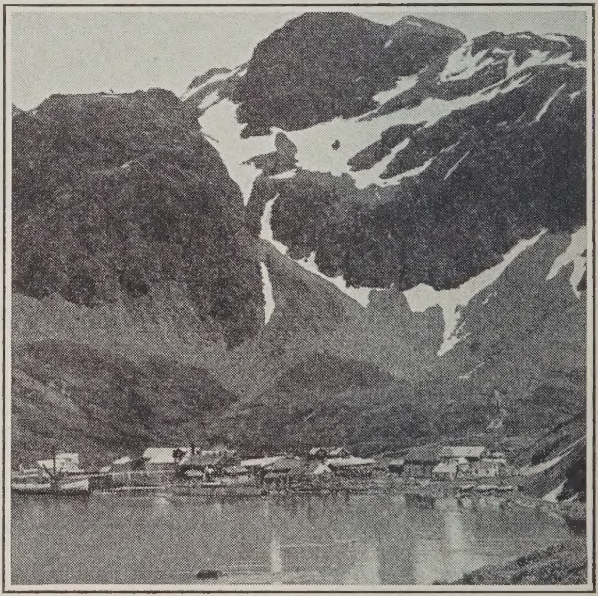


Courtesy Nat. Park Serv.

Fig. 311. In what ways is this fish-hook cactus fitted for life on the desert? (*Photo by H. E. Stork*)

Small animals have a better chance than larger ones. Ants are always plentiful and so are other insects that need little water for development. Centipedes and scorpions thrive, as do a few land snails that can plug up their shells and rest during the driest time. But there are relatively few species in the deserts where the struggle with the environment is so keen. *Exercise 4.*

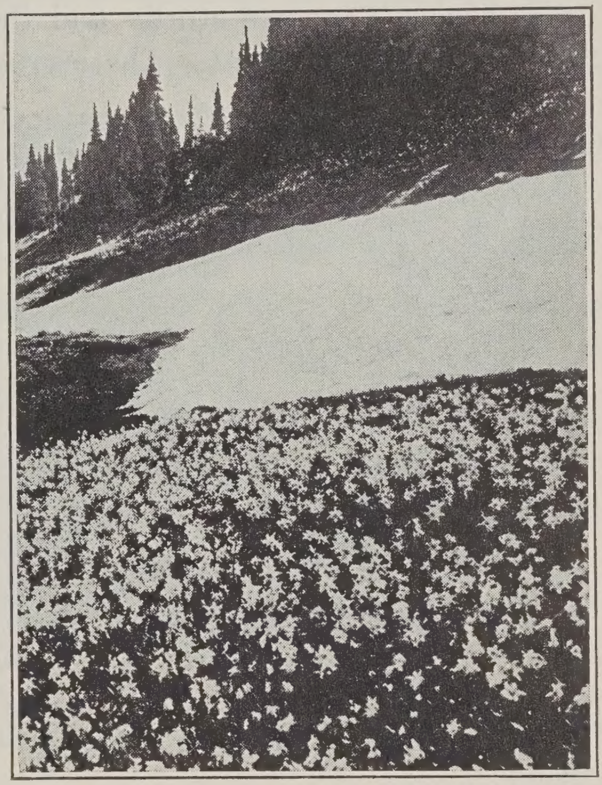
How do plants and animals meet the extreme cold of the polar regions? In both the arctic and the antarctic zones ocean life is rich the year round. Protozoa and small invertebrates are plentiful. Sea urchins and sponges live on the ocean bottoms; in the surface waters float bright microscopic plants (diatoms), sometimes coloring vast stretches of the sea. The diatoms serve as food to large numbers of Crustacea and snails. The abundant ocean fauna brings fish and birds, at least during the short summer season. Whales, too, live on the smaller food. The seal and the polar bear hunt for fish. With their large stores of fat and dense fur coats they can maintain a high body temperature even in the bitterly cold air and the frigid water.



Courtesy Am. Mus. Nat. Hist.

Fig. 312. In the Antarctic. Why must living things be scarce in such a region? (*Photo by R. C. Murphy*)

On land, the cold in the arctic zone is more intense. But under the drifts of snow and caps of ice the seeds of the hardier plants may survive. And as the days grow longer and the sun burns hot, many blossoms push through the snow. The patches of brilliant red and blue grow ever wider. The snow fields melt into lush green meadows. Life is no longer hard, for there are abundant sun and moisture for plants that can grow rapidly; slow-growing plants have no chance in the polar zones. Clouds of mosquitoes and midges rise from every little breeding pool. Certain flies are abundant. But in spite of the large numbers of blossoms there are few butterflies and moths. It takes too long to grow from egg to adult. Bees are scarce, too. Flowering plants depend largely on self-pollination and many plants depend on vegetative reproduction since they live too short a life to produce seeds.

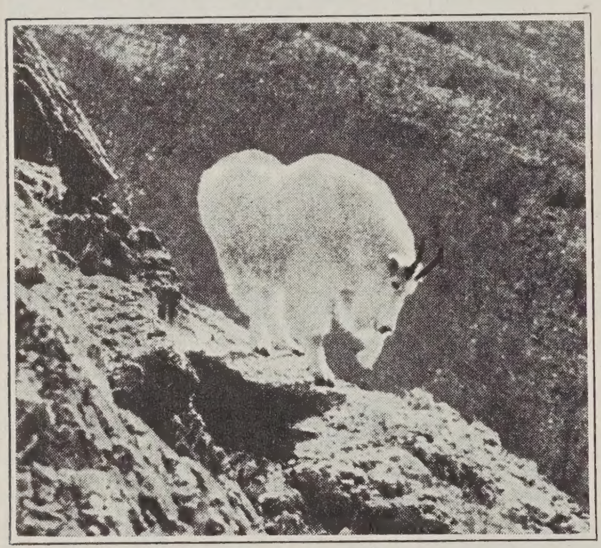


Courtesy U. S. Dept. Interior

Fig. 313. On the lower slopes of the mountain in Rainier National Park plants grow and bloom before the snow has disappeared. How does this help the species to survive?

The musk oxen and reindeer, which during the long dark winter months were obliged to nose out scraps of food under the snow and ice, now live in plenty and store large quantities of fat under the skin. The lemming and arctic hare grow fat on the juicy vegetation. Among carnivores, there are the ermine, fox, and wolf, but they are far less plentiful than the mammals that inhabit the sea, for there is little food for them. Land birds are not numerous. Amphibia and reptiles do not exist in these polar zones. Since their temperature is that of the surrounding atmosphere they cannot survive the winter cold.

The polar regions, for the geographer, are the regions of the arctic and antarctic zones; the biologist includes under the polar regions the tops of high mountains, too. For conditions of life on the highest peaks are much like those at the poles, but harder still. There is perpetual snow and ice. The cold is intense and strong winds blow almost constantly. But at somewhat lower altitudes the sun melts the edges of the snow fields during the hot summer months and carpets the mountain slopes with a dense arctic vegetation. Short-lived plants with brilliantly colored blossoms grow here. They are sturdy and they hug the ground, thus retaining all possible heat. The leaves are small and covered with dense woolly hair or hard waxy coats. When summer goes these plants die down to the ground.



Courtesy Canadian Travel Bureau

FIG. 314. How is the Rocky Mountain goat fitted for life among the rocks at high altitudes?

Rodents burrow in the ground and mountain goats and sheep roam over the steep hillsides, feeding on the lichens or hardy mosses which they can scratch out from underneath the snow. Their sharp little hoofs give them firm support on rocky cliffs and ledges.

Still lower down on the mountain side the flora becomes more varied. The evergreen trees and shrubs have climbed up to these heights, but those that grow in the highest places are dwarfs, sturdy and strong but stunted. They have been twisted by the steady winds. Only the hardiest have survived.

In its own way each of these environments, the regions of ice and snow, the deserts, and the depths of the sea, is a hard one for plant and animal life. Relatively few kinds of organisms have developed structures or habits which make it possible for them to survive these physical conditions. It is very different in the tropical and temperate zones. But even here organisms must meet the physical conditions of their environment. And since life is so much more abundant where conditions are less difficult, these organisms are faced with the need of escaping the many enemies which would destroy them and of competing with others of their own kind for the necessities of life.

Exercises

1. How may movement through water be made easier? Push your hand down through water with the palm downward. Now turn your hand so that it cuts downward through the water. What difference do you note? Explain. Have you proved anything? Is this an experiment? Why or why not?

2. *Demonstration.* What is the structure of the swim bladder of a fish? Dissect a large fresh fish. Turn aside all of the internal organs. Extending along the middle of the fish just under the backbone you will find the swim bladder. Insert a glass tube into it and blow air into it. What happens? What will be its condition when the fish is rising vertically? When it is sinking?

3. *Demonstration.* If the common water forms mentioned have not been demonstrated previously all those available in dried or preserved condition might now be studied.

4. If pictures of desert flora can be obtained, list all the striking characteristics of the plants you see. Which of these might be adaptations to their environment? Are you justified in saying that they are adaptations?

Problems for Classroom Discussion

1. Why has the northern midwest hot summers and severe winters?

2. Why does the water feel warm on the first cold fall day?

3. Why can plants and animals live at many different levels in the water?

4. Why is the crawl stroke used by swimmers who seek speed or endurance?

5. Why is it easy for a stout person to learn to float?

6. Does it make a difference where the swim bladder of a fish is located?

7. Why must stomata be lacking in a water plant if it is to live successfully?

8. Of what advantage is it to a water plant to have large air spaces?

9. Which would be a faster swimmer, an angler fish or a mackerel? Why?

10. Give several reasons why animals get scarcer in the lower depths of the sea.

11. Why are most deep-sea animals small?

12. Why are there likely to be more land birds in the arctic than land mammals?

13. Why can small plants grow where it is too cold for trees to grow?

14. What changes might take place in the flora and fauna if a desert region were irrigated?

15. How might you go through regions showing tropical, temperate, and arctic forms of life in a day's journey?

16. *Summary.* List the few most important ideas that you got from reading this problem without giving specific examples. Then test your knowledge of details by preparing a series of questions to ask your classmates. An example: If a plant has a waxy epidermis for what environment would it be adapted? Not adapted? Why?

Activities for the Junior Biologist

1. You can make a collection of water insects and transfer them to a class aquarium in which there are no fish. Use a net for collecting. If you find some insects feeding on others, separate them.

2. If you can, visit the shore to study and collect such forms as clams, mussels, barnacles, starfish, and sea anemones and seaweeds. Report.

3. Make an exhibit to illustrate the type of life found in the zone between tides. Use oyster and clam shells, dry starfish, barnacles, mussel shells, seaweed, and so on.

4. Look up and report on Beebe's descent in the bathysphere.

5. If you can interest a group of pupils who are talented with the pencil, prepare a mural illustrating the life at different levels of the ocean. Use large sheets of wrapping paper.

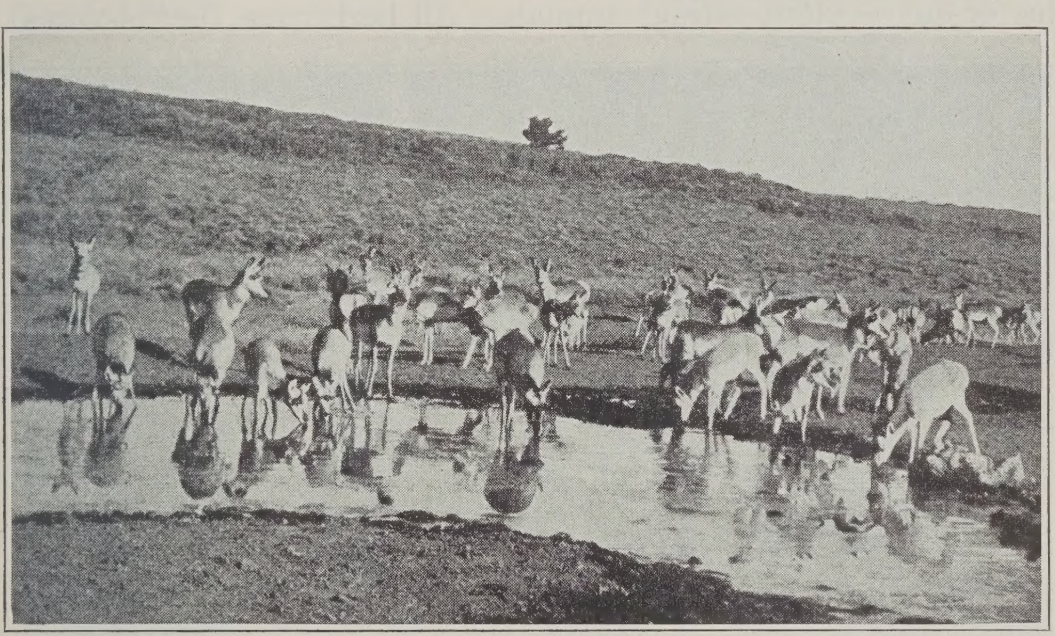
6. Prepare an exhibit to show the types of animal life found in the arctic.

Problem 2. How Do Organisms Injure One Another?

What kinds of enemies beset animals? Many animals eat other animals smaller than themselves. In fact, there is no animal too small to serve as food for other forms. Even those that cannot be seen with the naked eye are preyed upon by some kind larger than themselves. You will read later of complex "food-chains" in which each smaller animal serves as food for one larger than itself. This larger form is an ever-present enemy, usually alert and well equipped for the attack.

But how about the largest? Is it free from living enemies? Not at all. It is so conveniently large that smaller forms can live on its body or in it and devour it in tiny installments. An organism that furnishes food in this way to some smaller form is spoken of as a *host*. The one that makes its home in some other form or on it, thus obtaining nourishment from it, is known as a *parasite*. The parasite, the one that does the stealing, may be a protozoan or a much more complex form like a worm. Or it may not be an animal at all but a colorless plant.

Parasites are very common. They attack not only the large animals but also the small. As far as is known, all living things except the very smallest at the bottom of the scale may be hosts to parasites. There is much truth in Swift's famous lines:



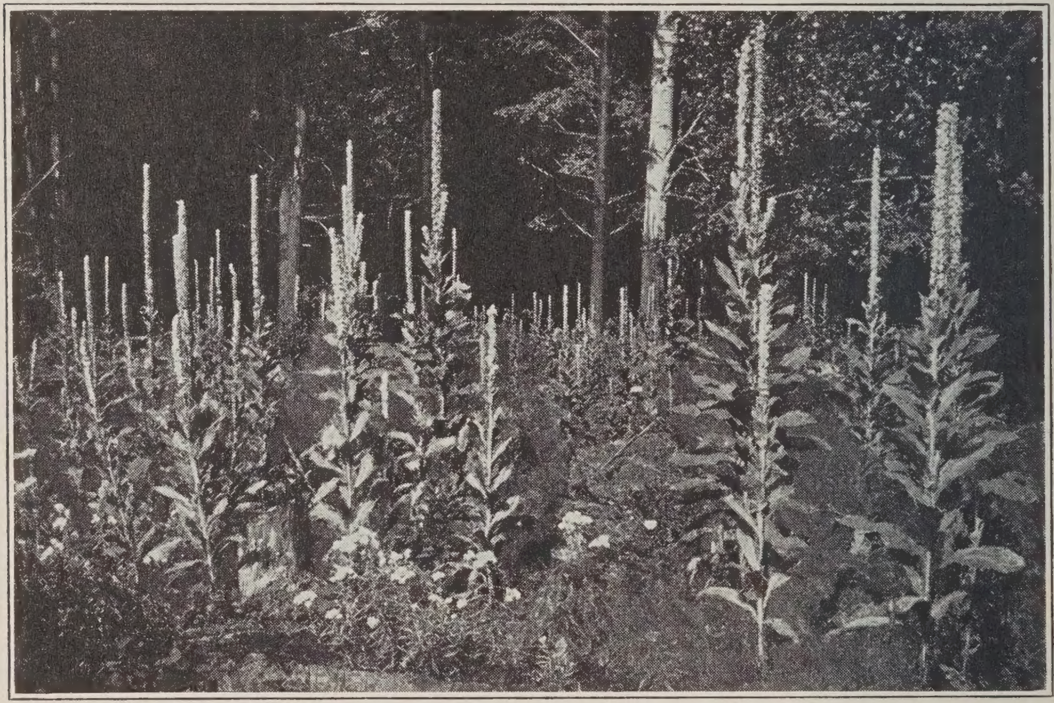
Courtesy U. S. Bur. Biol. Survey

FIG. 315. A herd of antelope on the Sheldon Refuge, Nevada. Against what competing organism is the antelope protected?

So, naturalists observe, a flea
Has smaller fleas that on him prey;
And these have smaller still to bite 'em;
And so proceed *ad infinitum*.

And every animal, large or small, has still another kind of foe: an organism that may never be guilty of a direct attack but that enters into competition with it. The necessities of life, such as food and a place in which to live, are often scarce and competition may become very keen. When pasture land is poor because there is little grass each grown sheep becomes the enemy of every other sheep, although they do not engage in a physical struggle. So, too, the hordes of locusts that settle on the vegetation become enemies of one another as the green leaves disappear. When trees have been stripped and grasses eaten to the ground, the bitter competition for food makes each insect the worst enemy of others of its own kind.

What kinds of enemies do plants have to meet? Plants have their enemies, too. Among them are the many herbivorous (her-biv′or-ous — plant-eating) animals. All herbivores (her′bi-vores) must eat enormous quantities of plant food in order to get sufficient nourishment; even a few will destroy comparatively large numbers of plants. And no matter how insignificant and weak the animal, it will attack and devour plants; often plants much larger than itself. The tent caterpillar may strip a cherry tree of its leaves, although each insect is much smaller than a single leaf. Then there are the many parasites which attack plants. Sometimes the parasites are animals; more often they are other plants.

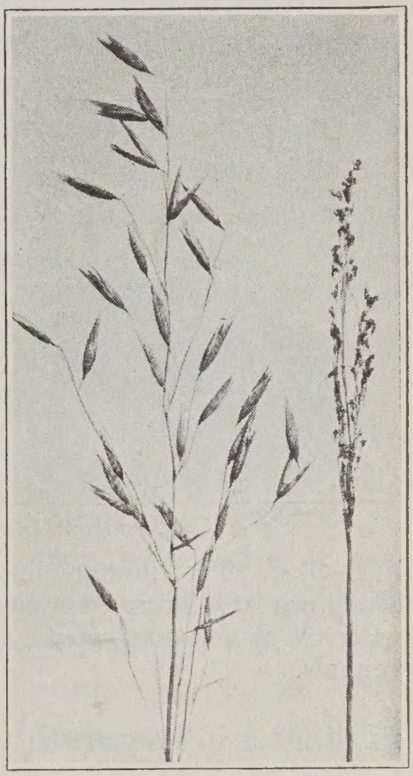


Courtesy Brooklyn Botanic Garden

FIG. 316. These tall stalks of mullein, a common weed, compete with one another and with the seedlings of the forest trees.

And again there is the passive enemy, for competition among plants is perhaps even more severe than among animals. Each plant has competitors for precious earth materials and for light. They may be members of the same or of different species. Those that can send their roots deepest into the ground, those that can grow where the sun either dries the ground or filters through in limited amounts, those that can scatter their seeds farthest will become formidable enemies to the less successful ones and will crowd them out.

These hardier plants that persist in crowding out their neighbors are called weeds. The ragweed, the shepherd's purse, the tumbleweed, the thistle, and the dozens of other weeds that line roadsides or clutter up flower beds, fields, and pastures are enemies of the less successful plants which they crowd out of existence. *Exercise 1.*

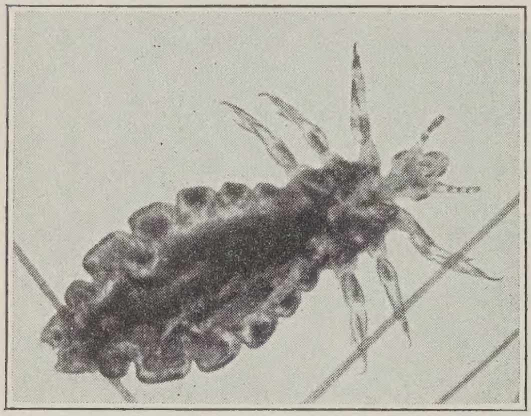


Courtesy Ill. Ag. Exp. Sta.

Fig. 317. The effect of smut on oats. Normal plant at the left. The fungus has a complicated life history since it forms different kinds of spores at different times.

In what ways may a parasite injure its host? In the cornfield there sometimes appear plants whose ears are black and sooty. These plants are the unwilling hosts of a parasite, itself a plant, known as corn *smut.* Smuts are fungi not so very unlike the common bread mold; that is, they consist of long branching threads called hyphae. The parasite may enter its host at any time throughout the growing season but most often it does so in the spring when the corn is starting out in life; then the hyphae grow up together with the tissues of the stem, drawing on them for food. In this case the corn plant is stunted but there may be no other outward signs of the parasites. Inside, however, the hyphae keep growing steadily and, as the kernels of corn form, the fungus pushes in and absorbs the stored starch. Using this rich supply of stolen food the parasite develops rapidly and prepares for its own reproduction. The hyphae, much as in the bread mold, divide into large numbers of black spores, which give the smutty appearance to the host. When ripe, these spores may be carried a long distance by the wind and fall on other plants over a wide area. Large numbers of corn plants fall a prey to this enemy.

Some parasites do not enter the host to spread throughout the organism but attack it from without. The scale insect settles on the surface of a leaf and sucks its sap. Plant lice often cluster on the soft stems of flowering plants and feed on plant juices. After they have pierced the skin, lice and fleas suck the blood of the animal that serves as host. Even the parasites which never enter the body may take so much food from the host that it finally dies. It is often difficult to decide when an animal is to be called a parasite. The term is used for animals such as those described because they are small and do not leave their hosts.



Courtesy Am. Mus. Nat. Hist.

FIG. 318. The human head louse. The lines are hairs. Closely related parasites attack dogs, goats, and other animals.

Often a parasite does more than steal food. It may form substances in its growth which are different from those within the host and poisonous to it. Bacteria living in another organism may form poisonous substances, called *toxins*. The toxins spread through the tissues of the host, whether man, or other animal, or a plant. Thus the parasites may kill the host and either die with it or escape to another host in which they repeat the process.

What are the different kinds of parasites that attack man? You have just read that man is host to some bacteria. You know that there are other parasites, like the louse, which attack man from without. You will read of larger parasites, worms of many kinds, such as the hookworm and the tapeworm, which enter his body and do damage in a variety of ways. There are also parasitic plants other than the bacteria, larger plants, which settle in the human body or on it. Certain yeasts cause diseases in man; one mold causes ringworm; another, athlete's foot. But there is still another group of animals some of whose members may be reckoned as serious enemies of man. These are the various protozoan parasites. In parts of Africa a common and much dreaded protozoan is the one that causes African sleeping sickness. One of the most widely spread of these tiny enemies is Plasmodium, which causes malaria. In British India alone this protozoan is said to attack 100,000,000 persons every year, often killing, sometimes only weakening, its victim. Whole populations elsewhere have been destroyed by malaria at various periods within the history of man.

How does the malaria protozoan injure man? In our country malaria occurs only in certain regions. The protozoan has no way of entering its host except by the bite of a particular kind of mosquito known as the *Anopheles* (an-of′el-ees), and Anopheles mosquitoes are rare in the northern United States.

The protozoan leads a complicated life, spending half of it in the blood of man and the other half in the stomach of the female Anopheles mosquito, which sucks the blood of man. It is always a female mosquito, since males do not bite. Once the protozoan has been introduced into man, it makes its way by a kind of gliding motion into one of the red corpuscles. In true parasitic manner it feeds on the proteins of the corpuscle, growing rapidly at the expense of the corpuscle. It becomes more rounded and shows a streaming of the protoplasm much as does the Ameba. After a day or two it has grown so much that it may completely fill the corpuscle. Then the nucleus divides a number of times, a little of the cytoplasm attaches itself to each nucleus and there are formed twelve or more small protozoan spores. Breaking through the membrane of the corpuscle, they are freed into the blood stream. With them are released the remains of the original corpuscle and probably toxins which have accumulated. It is at this time that the malaria patient suffers from the characteristic chills followed by fever. These symptoms are probably caused by the setting free of toxins. Each protozoan spore meanwhile repeats the cycle: it glides into a new corpuscle, feeds, grows, reproduces, and destroys the corpuscle. It is plain that when this has happened a number of times large numbers of corpuscles will have been attacked. The wholesale destruction of these cells soon shows itself in the patient. He is always tired, because oxygen is not being circulated properly for oxidation, and looks pale and anemic (lacking hemoglobin). If he should die, the parasites will die with him.

But in the meantime some of the parasites are likely to be saved from dying with their host by the activity of a female Anopheles mosquito. When a mosquito bites a malaria patient it may suck up some of the corpuscles containing parasites. Some of these have stopped reproducing and are changing in appearance. When they get to new surroundings in the mosquito's stomach they prove to be of two types, male and female. In the last unit you read how the male form swims to the female and fertilization occurs. Then the fertilized cell bores its way into the wall of the mosquito's stomach and, as you would expect of a fertilized cell, divides many times. The new protozoa produced in this way grow and a large swelling forms on the outer wall of the stomach to hold them. After some time this swelling bursts and many of the protozoa which are thus released in the body cavity of the insect reach its salivary glands. The next time the mosquito bites a person some of the parasites will enter with the bite.

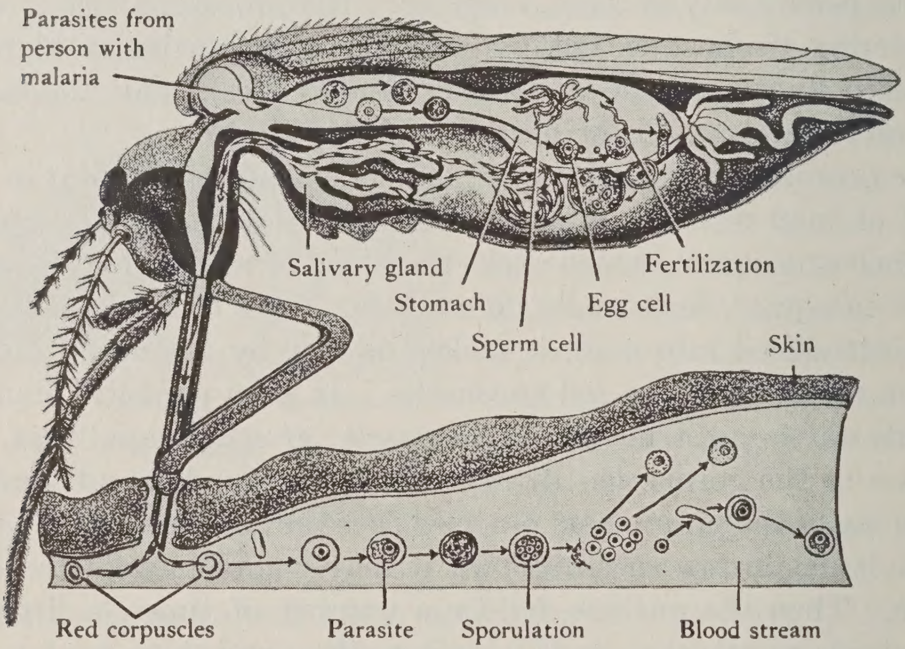


FIG. 319. Lower part of diagram shows section through skin with malaria parasites being introduced into the blood. Trace the changes in the parasite while in the human body. Now study the mosquito. It had bitten a malaria patient some time ago. Why can it put parasites into the pierced skin?

How was the cause of malaria discovered? The story of the discovery of the protozoan in the blood corpuscles of man and in the stomach of the mosquito is a long and interesting one. As in the case of most scientific discoveries many scientists contributed their share. In 1880 Alphonse Laveran, a French army surgeon in Algeria, described the parasite which he found in the blood of malaria patients. Italian investigators confirmed this discovery. But how the parasite got there no one knew, so this discovery by itself was not of great importance.

But about fifteen years later an English investigator, Dr. Patrick Manson, suggested that the mosquito might be responsible for transmitting the parasite to man. He had shown the role of the mosquito in transmitting another tropical disease and it had been known for centuries that malaria occurs where the country is swampy and that mosquitoes breed in swamps. Acting on these suggestions, a British army surgeon in India, Dr. Ronald Ross, studied the mosquito to find traces of the parasite. After two years of patient search he was about ready to give up when he discovered parasites which he believed might be those of human malaria in the Anopheles mosquito. These laboratory demonstrations, however, were no proof of the connection between malaria and mosquitoes. It remained for the London School of Tropical Medicine and for a number of Italian investigators to perform experiments to prove that man gets malaria through the bite of a mosquito which carries the particular parasite and furthermore that man can get it in no other way than this. Some of these experiments were performed in the malarial regions near Rome and some in England. *Exercises 2, 3.*

How do more complex animals live as parasites in man? There are several round worms that are serious enemies to man. One of them is the *hookworm* which is found in our southern states. This parasite saps the strength of its victims and makes them feel tired and lazy. It may attack people all over the globe where the climate is suitably warm; apparently it has been doing so for thousands of years, certainly since the days of the early Egyptians. The worm attaches itself to the wall of the intestine and feeds upon the blood. In puncturing the intestine it injects a substance which keeps the blood from clotting. This is helpful to the parasite but not to the host for in this way the victim keeps on losing blood even after the worm has stopped feeding. When the parasite reproduces, the eggs pass out of the intestine with the excretions. Thus the eggs get into the soil. In the soil, the egg hatches into a larva which is fitted for boring through human skin. People going barefoot are thus easy victims. Once in the body, the hookworm enters the veins, is swept to the heart, and from there to the lungs. Again it bores. This time it enters the air passages, incidentally damaging them and making them susceptible to tuberculosis. From the windpipe it passes into the alimentary canal where it spends the rest of its life and where, as you just read, it does great harm. Now that its life history is known precautions can be taken to kill off the larvae in the soil and shoes can be provided for people who cannot afford to buy them. Drugs have been discovered, too, which make it possible to rid the body of the adult worm. The hookworm is no longer a menace in those regions in which education has spread and a higher standard of living has been established. *Exercise 4.*

Trichinosis (trick-in-oh′sis) is a disease caused by a relative of the hookworm. The parasite lives in the muscles of man and also in the muscles of the pig and the rat. You can get the disease by eating the meat of a pig that carries the worm. Unless pork is thoroughly cooked, the parasite, buried deep among the muscle fibers, escapes death. If such meat is eaten, the worms are dissolved out in the intestinal tract, reproduce, and then burrow into the muscles where they come to rest. It is fortunate that trichinosis is not common for it is extremely painful and sometimes proves fatal.

But the parasite of which you have probably heard most often is the tapeworm, some species of which make man their host. It, too, has a larval stage which lives in the flesh of various animals, most frequently in the pig. Fresh water fish also give shelter to one type of tapeworm larva and have been known to pass on their parasite to man. The worm, having entered the human body, fastens itself to the wall of the intestine by means of the hooks and suckers on its head. There it stays, absorbing the digested nutrients by which it is surrounded, and devoting itself to the production of segments filled to bursting with fertilized eggs. The parasite uses up the nutrients the host needs and damages the intestinal wall, but the injury is relatively slight for a man may live on, though not very happily, with a twenty-foot tapeworm inside his intestine.

What injuries are inflicted on plants and animals by their enemies? You have seen that the enemies of every plant and animal are much more varied and numerous than you might suspect. Most organisms have visible enemies that attack and devour them completely or in large part. Most have the enemies that eat the same foods and seek the same living quarters. But besides all these, both animals and plants have enemies smaller than themselves that are parasites. The parasite may be an animal or a colorless plant. It may do its damage by drawing on its host for food, slowly or quickly. It may also damage its host in a number of other ways, most important of which is the formation of poisons or toxins. It is not surprising that, being surrounded by so many enemies, many kinds of plants and animals have developed many different means of defense. Those species that happened to develop suitable means of defense survived; many of the others died. For this reason the plants and animals with defenses are plentiful.

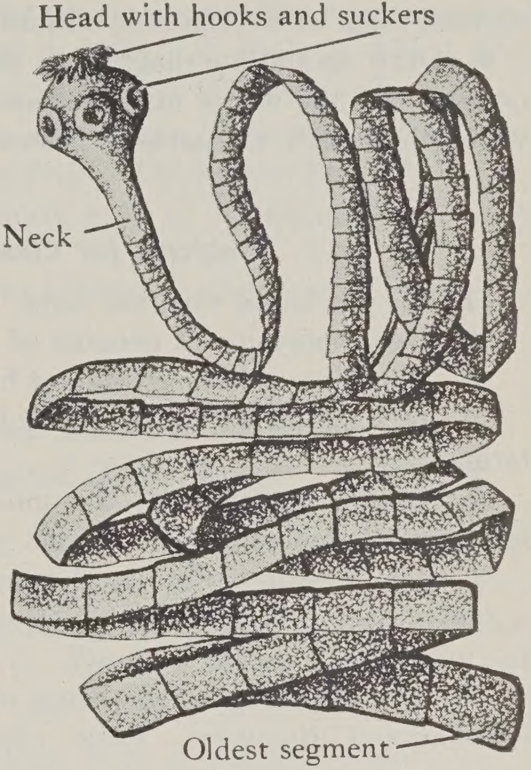

Head with hooks and suckers
Neck
Oldest segment

FIG. 320. The tapeworm is an ugly-looking visitor. It is easy to get rid of, however.

Exercises

1. What is the effect of crowding upon the growth of plants? Plant seeds of a rapidly growing plant very close together in one pot; space seeds far apart in another pot. Observe their growth for several weeks. What differences do you note? Explain why it is important to weed your garden.

2. There was an old and common belief that damp night air could cause malaria. How much truth is there in the belief? Were the observations made by the people of those early days correct or faulty? Discuss fully. Was this old belief a help or a hindrance in arriving at the truth?

3. You now know that (1) malaria is caused by a protozoan carried by mosquitoes, (2) mosquitoes breed in swamps, (3) Anopheles mosquitoes fly and bite only at night. It was proved that malaria can be acquired only through the bite of an Anopheles mosquito. Outline the experiments that must have been performed to establish this fact. Present them to the class for criticism.

4. Draw an outline diagram of the human body, indicating the chief organs. By the use of arrows show on your drawing the parts through which the hookworm parasite passes.

Problems for Classroom Discussion

1. Do you think that the term "host" is well chosen? Explain.

2. How many insect enemies of plants can you name?

3. Why does a farmer thin out his garden?

4. Is toxin-formation an advantage or a disadvantage to the bacterium?

5. Within recent years the mold which causes athlete's foot has spread with great rapidity. Why?

6. The mosquito's life is short. How does the protozoan profit by spending part of its life in man? How does the protozoan profit by using the mosquito as its second host?

7. The discovery of the cause and transmission of malaria was an international discovery. State which nations contributed and how, making one complete story to include all the facts.

8. Give two reasons why pork and pork products (frankfurters, etc.) should not be eaten except at home or in a reliable restaurant.

9. Are meats inspected in the community in which you live? If you are in doubt about this, what precautions should you take?

10. A tapeworm has male and female reproductive organs within the same individual. Of what importance is this?

11. Parasites seem to be common. In which groups of animals and plants are there species which lead a parasitic life?

12. *Summary.* Can you present facts to support each statement in the last paragraph of this problem? List the statements in your notebook and add the facts.

Activities for the Junior Biologist

1. Dissect insects like grasshoppers and crickets to see if you can find any wormlike parasites in them. Make a report of your findings to the class.

2. Look up the structure of such parasites as Sacculina (a parasite of the crab) and the tapeworm. How do biologists explain the absence of certain organs?

3. For an interesting account of the effect of parasites on history, read Zinsser's *Rats, Lice and History*. Prepare a report to be read in class.

4. Look up and report on parasites of man not mentioned in this problem. In what parts of the world are these parasites most common?

5. Dodder is an interesting plant parasite. If you can find dodder read up about its habits and show a specimen to the class.

6. Collect weed seeds and in the spring mix them with flower seeds and plant in a box. Which come up first? Which grow fastest?

7. Report on the Reed Commission's work in the conquest of yellow fever.

8. Report on the work of the Rockefeller Foundation in combating hookworm disease.

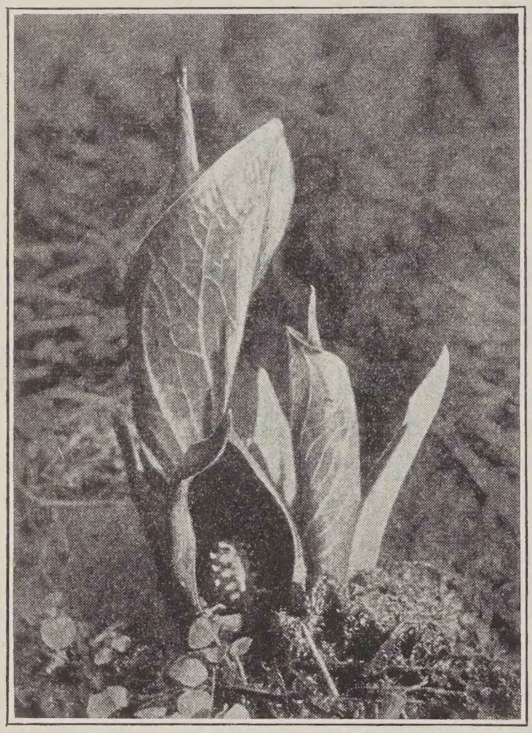
Problem 3. What Means of Defense Do Plants and Animals Use against Their Foes?

How do the defenses of living things vary? A plant or animal species which has successfully kept itself alive despite the hardships of its environment and the competition of its enemies must have many means of defense. It must be protected by devices which prevent other organisms from eating it or it must be so prolific (produce so many offspring) that it may be eaten freely and yet hold its own. It must be able to escape parasites or possess ways of defeating them once they have gained entrance to the body. How some plants and animals have solved this problem will be indicated in the paragraphs that follow.

What weapons are used by plants against plunderers? The firm, needle-pointed thorns of the rose and the tearing brambles of the blackberry might well be discouraging to many animals, but the weapons that seem so effective to man are rarely completely enemy-proof; donkeys eat thistles and seem to relish them. Even some varieties of cactus, if they are not too spiny, tempt animals with their moist fleshy stems.

Many of the nettles are covered with innocent-looking hairs which prove to be more than they seem. The sharp, downward-pointing hair pierces the skin, breaks off and discharges an irritating substance that causes a burning sensation which may last for many hours. In other plants, as in the mullein, the hairs do not have poison glands but grow so close together that the feltlike leaves are generally avoided by grazing animals.

The milkweed, too, smooth and juicy as its leaves may be, stands unmolested except by the caterpillar of the Monarch or milkweed butterfly. Its defense is a different one. Through its stems and leaves flows a bitter white sap. There are many plants that seem to be bitter or otherwise distasteful to some animals. Other plants may contain poisons. An animal that stripped a poisonous nightshade of its leaves might pay the penalty with its life.



Courtesy Nature Magazine

FIG. 321. The skunk cabbage, the earliest spring flower, is left alone by animals. If you have ever crushed a leaf, you will know why this is so. (*Photo by B. L. Brown*)

Sometimes the poison may be one that need not be swallowed to take effect; it may enter the body through the skin, as in the poison ivy and the poison sumac and their cousin of the western states, the poison oak. *Exercise 1.*

How do animals protect themselves against their enemies? Since, by and large, animals have the power of locomotion, their defense lies to a great extent in strong muscles, flexible joints, keen senses, and quick reactions. But they have special weapons, too. And the weapons which are used for defense are often employed for offense against the animal sought as food. Many animals, unlike plants, must go out to capture their food. Carnivores (meat eaters) are animals with sharp, powerful teeth but almost all mammals can use their jaws to good advantage; even the dull teeth of grazing animals can inflict severe wounds. Some reptiles and many fish are equipped with strong jaws and sharp teeth. The swordfish has the upper jaw enormously lengthened. It apparently uses the sword as a harpoon or it may, when it meets a school of small fish, thrash about and kill its prey by striking them with the sword. Even toothless jaws can be dangerous weapons. The eagle and the hawk can tear their prey to shreds with their hooked beaks. It is said that a large snapping turtle can bite through a wooden plank.

Sharp claws often accompany strong jaws. Even a bear, whose claws look relatively dull and harmless, can rip through the clothing and flesh of a man. Careless visitors to the national parks have been injured when a tame bear, eager for food offered to it, rested its paws against the visitor's chest. In many animals in which the toes are reduced in number there is a hoof which is sharp and hard.

Some mammals have horns and antlers. Some, like the porcupine, have sharp quills barbed like an arrow, quick to pierce the flesh and difficult to draw out. These quills, contrary to common belief, cannot be flung out; they are loosely attached and come out when touched.

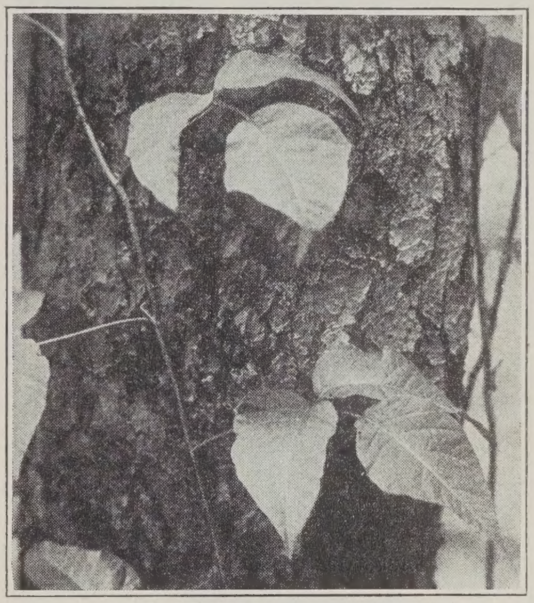
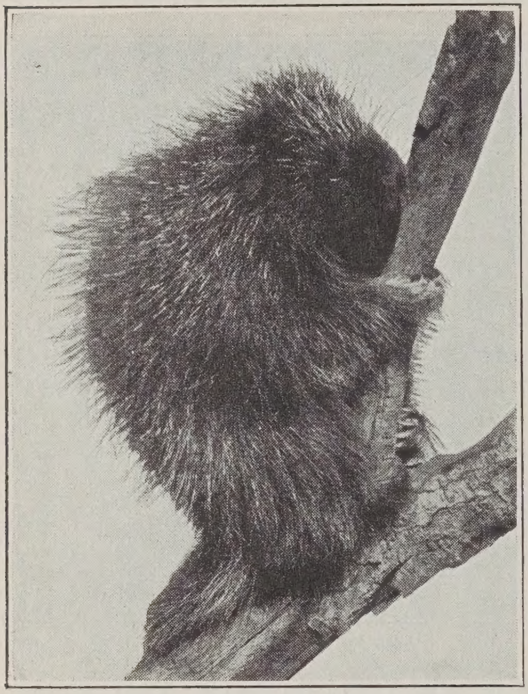


Photo by H. Schneider and J. Schwartz

FIG. 322. Poison ivy. How many leaflets has the leaf? The margin may be somewhat more toothed than in this photograph. The berries are gray. The leaves are bright and shiny.

The skunk, of course, has a simple and effective device not common among mammals. Some insects use this device. The well-named stinkbug cannot work at long range, it is true, but in its small way it is as unpleasant as the skunk. You may never have seen these small shield-shaped insects but if you have ever eaten raspberries you have probably become well acquainted with them. As they crawl over the ripe berry they leave behind a trail of fluid whose taste is unmistakable. Many kinds of insects are believed to secrete substances within themselves that render them unpleasant to birds.

Some animals have true poison glands. Among vertebrates they are of rare occurrence. The Gila monster and the few poisonous snakes have hollow fangs at the base of which lies the poison gland. In fish, there are sometimes poison glands at the base of special grooved spines forming part of a gill cover or of a fin. Among insects and spiders poison glands are not uncommon. The amount of poison secreted by them is so small that usually it has little effect on a large organism such as man. But used against small prey tiny doses may be very effective. And there are all kinds of devices for injecting it. Biting flies and mosquitoes have special mouth parts for this purpose; and so have ants. Spiders have the glands at the base of their first pair of appendages, which are like jaws. Bees, wasps, and their relatives use an ovipositor, the egg-laying apparatus, for stinging. This is a long tube which projects from the tip of the abdomen, ending in a sharp point. When a poison gland is attached to the ovipositor it makes an excellent weapon, though, of course, only the female carries it.



Courtesy N. Y. Zool. Society

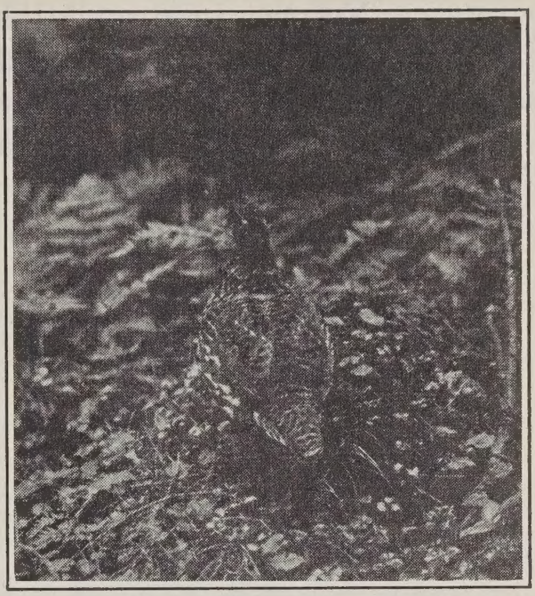
Fig. 323. One of the slowest and dullest of mammals, the porcupine survives because of its special weapons.

In the group which contains the jellyfish and the sea anemones poisonous secretions are common. The poison generally serves to paralyze and capture the smaller prey, but at other times, as when the jellyfish stings the bather, it is an effective weapon of defense. In these animals, there are microscopic lassolike hairs charged with poison. These are shot out from special cells. There are so many thousands of them that, small as they are, their poison can cause severe swelling in man. Some protozoa also have poisoned lassos constructed on a still smaller scale.

These are the obvious weapons that animals use both for defense and for offense. But some have developed more unusual devices. The electric eel carries batteries under its skin with which it can give powerful shocks. The cuttlefish and the octopus, although their tentacles are excellent weapons, use a strange device for escaping larger animals. They pour out a cloud of inky material which acts as a smoke screen and hides them from the enemy. By the time the protective substance has diffused away the animal has made a sharp-angled turn and disappeared.

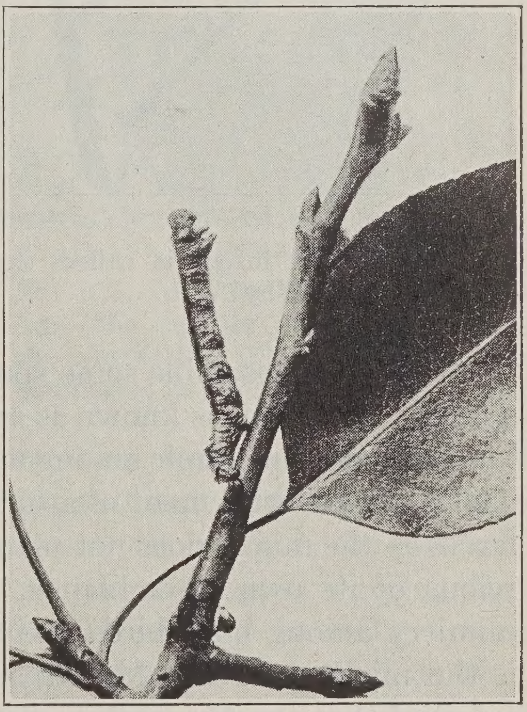
When does a warning suffice for protection? It is interesting to note that powerful weapons are often associated with warnings of one kind or another. The rattlesnake need rarely use its poison fangs, for its sharp rattle serves to clear its path. The coral snake does not make itself heard but strikes the eye with its bright rings of red and yellow and black. The black and yellow fire salamander is so startling in its colors and its markings that its enemies must be pretty dull to need more than one unhappy experience with its unpleasant milky secretion. Even so innocent a gesture as raising the hair on its back enables the cat to warn the dog that it is not to be trifled with.

How can animals without weapons of defense survive? Those animals that happened to develop without any defensive tools or instruments would be the first to fall prey to some larger organism. They would be devoured and the species would soon become



Courtesy Am. Mus. Nat. Hist.

Fig. 324. Spruce grouse on the ground. Of what advantage are the mottled brown markings on the feathers?



Courtesy Am. Mus. Nat. Hist.

Fig. 325. Can you find the geometrid moth caterpillar in this picture? Its color is like that of a twig, and it holds itself at this angle all day. It moves about and feeds at night.

extinct. Yet there are some that have survived. And in many of these cases, unless there is some other good biological explanation for their survival, you will find that such animals are inconspicuous in the particular surroundings in which they live. They are colored, and marked, and sometimes even shaped in such a way that they will escape notice. This is particularly true of many insects, although one finds evidences of *protective resemblance* in each of the animal phyla.

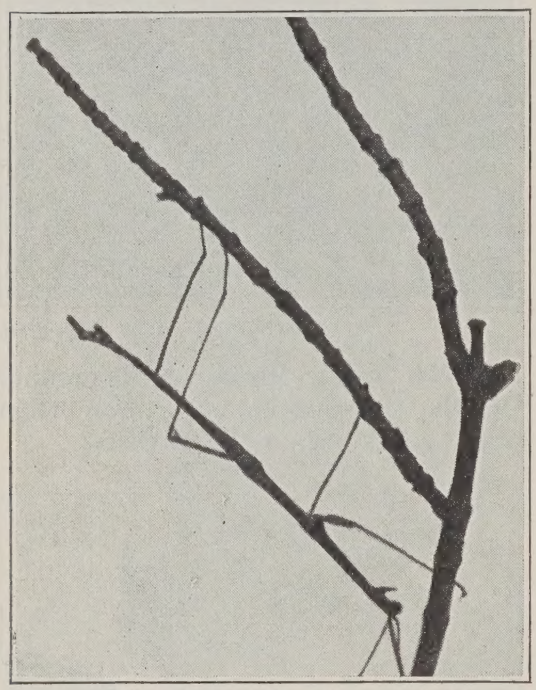


Photo by H. Schneider and J. Schwartz

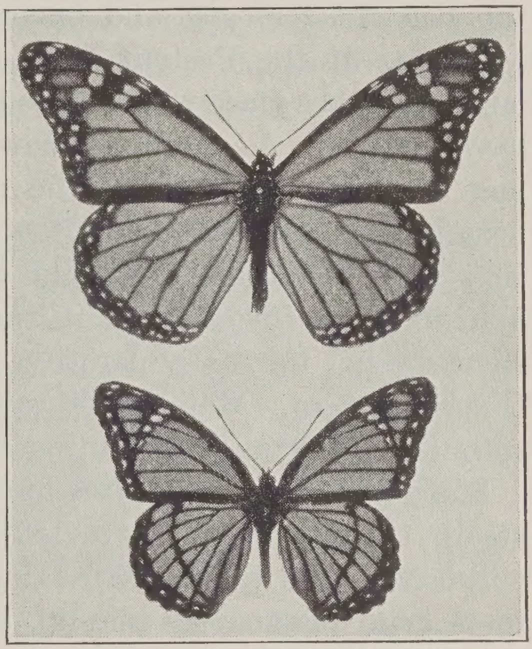
Fig. 326. This insect is called the walking stick. Why?

It is readily observed that leaf insects are often green, and those that settle on bark are brown or gray, often spotted. Some show a more striking protective resemblance. The famous Kallima butterfly of the East Indies, when resting, folds up its wings which are bright above and dull below; it then looks like a dead leaf.

There are other defenseless animals which survive, not because they remain unobserved, but because they are colored and shaped to resemble some species that is well protected in some special way. This is known as *mimicry* (mim′ik-ree). As someone has well said, the mimic among animals is like the businessman who copies the advertisement of a successful firm. But there is this difference; the mimic does not plan to fool anyone nor is it even conscious of its own resemblance. There are striking examples of mimicry among both birds and insects. One of the most famous is the mimicry of the Monarch butterfly by the Viceroy. It is believed that the Monarch is distasteful to birds while the Viceroy is not. The Viceroy is thus protected because it cannot easily be distinguished from the Monarch.

In his travels on the Malay Archipelago, Alfred Russel Wallace discovered that near some large aggressive birds that could hold their own against their enemies lived weaklings similar in appearance but of a different species. And where on a neighboring island there was a variation of the strong, fighting bird, there was always found a slightly different mimic to correspond! *Exercise 2.*

How does the animal protect itself against an invisible foe? When it comes to the invisible parasite (in most cases a bacterium) a new problem arises for the victim or host. All the weapons, instruments, and devices mentioned in earlier paragraphs are of no avail against a bacterium too small to be met in open battle. You cannot impress an invisible foe with warning colors or sounds when sense organs for perceiving these are lacking; nor will it help you to hide from him when he does not search you out but stumbles on you by accident. To ward off microorganisms (microscopic organisms) the animal must be so constructed as to make entrance difficult. Most of the vertebrates are fortunate in possessing a substantial covering of scales or feathers or hairs. But there are openings into the body, such as the mouth and the nose, which make it possible for the smaller parasites to enter. In man and many other animals these cavities are so made that they stop large numbers of bacteria. Of those that succeed in reaching the stomach, a considerable proportion is killed by the acid digestive juice. But in spite of all this, microorganisms, especially bacteria, are so numerous that large numbers escape these methods of defense.



Courtesy Am. Mus. Nat. Hist.

FIG. 327. In color as well as in markings, the smaller Viceroy resembles the Monarch. What differences can you detect in their markings?

There is still another way for bacteria to enter. It happens at times that the skin is broken by some foreign object or pierced by an animal. Then the parasite may enter directly into the tissues where it is likely to find favorable conditions; for food is available, there is moisture, and the temperature is frequently suitable.

How may the animal destroy bacteria that succeed in entering the body? Of course, not all microorganisms are fitted for growing inside an animal. But in this paragraph you will read only of parasitic bacteria. They are often called *pathogenic* (path-o-jen′ik — disease-giving) bacteria. Once inside the body, the pathogenic bacteria multiply rapidly. The host would soon be conquered did it not have some way of resisting. It is equipped with two types of defense. One was discovered by Eli Metchnikoff (1845–1916), the Russian zoologist and bacteriologist. With the help of his assistants at the Pasteur Institute in Paris, Metchnikoff found out what takes place where there is a break in the skin and bacteria have entered. As the blood flows by this break white corpuscles pass through the walls of the capillaries and enter the tissues near by. Here they destroy the bacteria by eating them. Since they form pseudopods like the Ameba the white corpuscles are able to move freely about in the tissues, engulfing bacteria. If there are not too many parasites the white corpuscles soon rid the tissues of them. Metchnikoff called these white blood cells *phagocytes* (fay′go-sytes — devouring cells), because they eat bacteria.

Sometimes the phagocytes have no luck with the bacteria; instead, they themselves are killed by the smaller germ. More corpuscles enter the tissues at this spot; if they too die, more and more dead phagocytes pile up, blocking the circulation. This is what happens when pus forms in a wound. The pus, when examined microscopically, proves to be a mass of dead phagocytes containing large numbers of living bacteria.

The white corpuscles of the blood may in this way engulf and digest not only bacteria but animal parasites and foreign particles of all sorts. Phagocytes are useful. But if an animal were obliged to depend solely on its phagocytes to fight pathogenic bacteria it would be successful against only a few kinds. It has still another means of defense.

By what other means can the animal defend itself against microorganisms? It used to be thought that pathogenic bacteria did their damage by multiplying in the body to such an extent that the circulation was blocked and organs could not perform their functions. This does happen in a few diseases. But as a rule it is not the presence of bacteria which injures the body of the host but the presence of toxins, poisonous substances made by the parasite. Certain kinds of bacteria excrete these toxins; others keep the toxins within their own cells, but in the end the poison does just as much harm, because when the bacterium dies and breaks up the toxin gets out. You can see, therefore, that the animal body needs something more than phagocytes in fighting bacteria. It needs to rid itself of the toxin as well as of the bacteria themselves.

Toxins are disposed of by means of substances which, when present, are in the plasma of the blood. These substances combine with the toxin and neutralize it; that is, make it harmless. They are called *antitoxins* (an-ti-tox′ins). Antitoxins are secreted by various connective tissue cells. The venom of snakes and some of the deadly poisons made by higher plants are like the toxins secreted by bacteria. And the animal can make antitoxins against such poisons, too. You will hear more about antitoxins in the next unit, especially in connection with diphtheria.

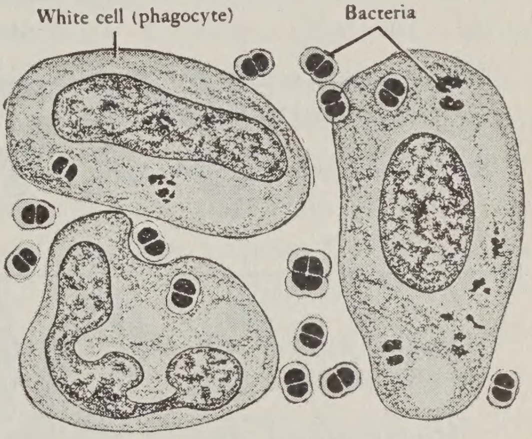


FIG. 328. White cells (phagocytes) destroying bacteria by engulfing and digesting them.

What other protective substances are found in the plasma? Besides the antitoxins there are other substances dissolved in the plasma which help the animal fight against the bacteria that have entered its body. These other substances work on the bacteria themselves, not on their toxins. There are, for instance, certain substances which act on the bacteria in such a way that it becomes easier for the phagocytes to eat them. Such substances are called *opsonins* (op′so-nins — meaning "I prepare food for"). If there are large amounts of an opsonin in the plasma the percentage of engulfed bacteria digested by the phagocytes is great. Some opsonins seem to prepare any bacterium for ingestion; others will act on only one species of bacterium. Such opsonins are said to be *specific.*

Other chemical substances in the blood do not assist the phagocytes but affect bacteria in different ways. Among them are the *lysins* (ly′sins), which dissolve bacteria. In fact, not only bacteria but all kinds of foreign cells, whether red corpuscles or other cells, taken from one animal and injected into the blood stream of another may be dissolved by lysins. As in the case of some of the opsonins, there is a particular lysin which is called forth by each kind of foreign cell; that is, lysins are specific. Then there are *agglutinins* (a-glue′tin-ins), which gather the bacteria together into clumps. If the bacteria are the kind which have the power of motion, the agglutinins make them come to rest. Just how this helps the body is not altogether clear. Perhaps when brought to rest in groups bacteria are more easily attacked by the phagocytes.

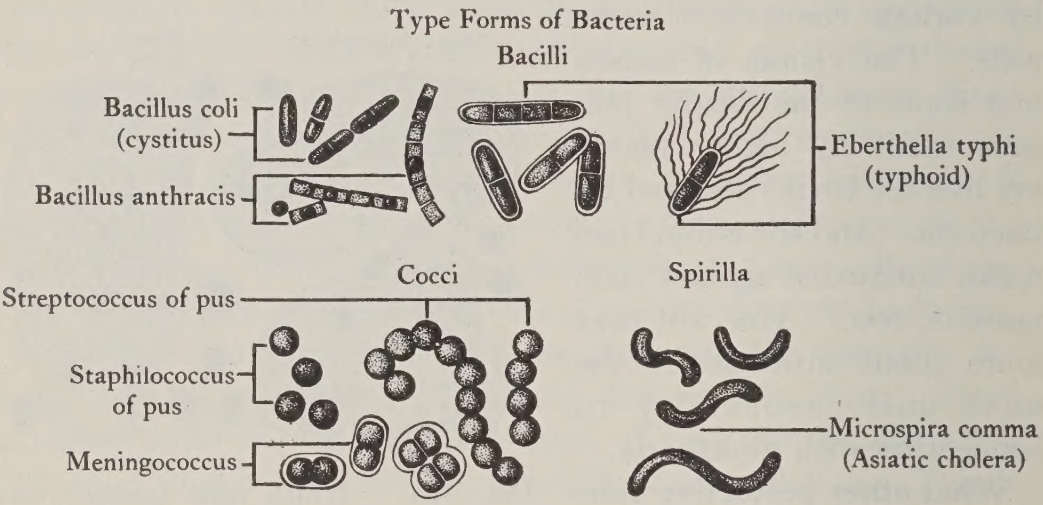

Type Forms of Bacteria
Bacilli
Bacillus coli (cystitus)
Bacillus anthracis
Eberthella typhi (typhoid)
Cocci
Spirilla
Streptococcus of pus
Staphilococcus of pus
Meningococcus
Microspira comma (Asiatic cholera)

Fig. 329. Bacteria are divided into three main groups according to shape. What are these three groups called? What variations in shape can you find within each group?

What is meant by acquiring immunity to disease? All these substances dissolved in blood plasma which act against bacteria or the poisonous products of bacteria are spoken of as *antibodies.* Among the antibodies discovered up to the present time are antitoxins, lysins, agglutinins, and opsonins. Phagocytes, of course, are not considered antibodies since they are not dissolved substances but living cells. Antibodies differ from phagocytes, too, in that most of the antibodies are specific; there is almost always a separate antibody for each species of bacterium or the products of that species. When an animal's cells have protected it against the special bacterium by means of a special antibody the animal is said to have acquired *immunity* to that disease; it does not fall a prey to that parasite.

How long does acquired immunity last? After the antibodies have formed they remain in the blood plasma for varying periods of time. While they are present each makes the body more resistant to a particular bacterium. In the case of some diseases, such as influenza, immunity lasts but a very short time; in other diseases immunity lasts for many years. In such cases it seems that the connective tissue cells, having once made the special antibody, go right on doing so. Also these tissue cells have been made more sensitive so that when, later in life, more of the same kind of bacteria happen to enter, the cells produce antibodies more quickly than before and, probably, in larger amounts.

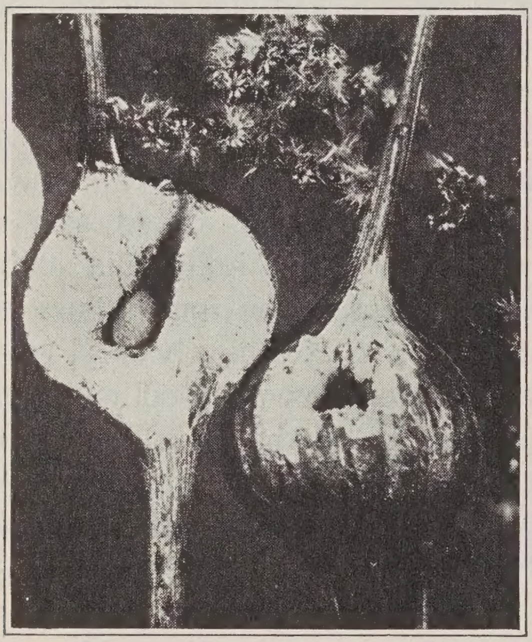
Long before antibodies were discovered it was known that a person may acquire lasting immunity to some diseases; when a child has had whooping cough or scarlet fever he rarely gets it a second time. In fact, the early records of China and India show that people were making use of this information four thousand years ago. When there happened to be a particularly mild epidemic of smallpox they would deliberately expose their children to it, knowing that when they had once had it they would not get it a second time. In the next unit you will learn how scientists nowadays, since they understand more about antibodies, apply this knowledge scientifically. They help persons to acquire immunity under carefully controlled conditions.

What is meant by natural immunity? Sometimes it would seem that the entering bacterium is not exactly suited by conditions in the host. No two bodies are exactly alike chemically. A bacterium entering one person may find conditions perfect. The tissue cells and body fluids of another person may be less suitable for the bacterium. The bacteria that enter may die or they may remain alive but do no harm to the body. Sometimes it happens that not only an individual but a whole species is able to resist the attack of some special kind of bacterium. Such organisms have a *natural immunity* to these bacteria. Many cases of natural immunity to various diseases have been noted in man.

In cases of natural immunity it may be that conditions in the body are unsuitable for the parasite because the connective tissue cells are unusually sensitive to this particular bacterium and therefore unusually quick in making their antibodies. But natural immunity is not well understood.

In some cases, what appears as natural immunity is really immunity acquired early in life. The child, while it is young, suffers so mild an attack of the disease that it is never noticed; but the connective tissue cells react to the bacteria and produce the necessary antibodies.

How does the plant protect itself against the entrance of microscopic forms? The farmer and gardener are all too well aware that plants are subject to many kinds of diseases. You have read about rusts and smuts attacking wheat or corn or rye. Wild plants fall prey to diseases too. The organism that attacks is generally one of the larger fungi but may be a bacterium. The plant, like the animal, responds to the parasite. In some cases the parasite stimulates the cells to rapid growth and a swelling forms which walls in the parasites. Such swellings are called *galls*. Plants may form galls also in response to the sting of an insect when it inserts its egg together with a drop of poison. No doubt plants form antibodies of various kinds, too, but little is known about them.



Courtesy Am. Mus. Nat. Hist.

FIG. 330. The swellings on these goldenrod stems are galls. The one cut open shows the insect developing inside. (*Photo by M. C. Dickerson*)

What means of defense have been developed by many plants and animals? The variety of weapons of defense is infinite. Every device that your ingenious mind might invent may be found in some animal or some plant somewhere on this earth. Similar devices are often found in animals of very different phyla. Spines, spears, and poisoned darts are very common, in both plants and animals. In the protozoan they are microscopic; it lives in a microscopic world. In the sawfish the weapon may be five feet long. Tentacles to ensnare and strangle the enemy are found in the octopus, huge tentacles twenty feet long. But there are just as dangerous tentacles in the microscopic Arcella, a relative of the Ameba. Ill-smelling and ill-tasting substances are frequent in plant and animal. Some of these substances are harmless, others are deadly poisons. They may be found throughout the tissues of the organism, making all the cells a source of danger to the enemy that attempts to eat them; they may be secreted by a few cells forming special glands in some particular part of the body.

Then there are the animals which have no weapons, those that hide. Sometimes it is a dull coloring that serves them best; at other times, in other surroundings, it is contrast and bold markings that put on them the cloak of invisibility. There are those that bluff, those that swagger and talk big and keep their hands on their hip pockets ready to draw the pistol that is never there.

But most interesting of all is the response of the organism to its invisible enemy. Here, even the largest animals must have invisible weapons since they are fighting a microscopic foe. They keep on hand a well-trained army of phagocytes. And this they reinforce with a chemical warfare employing a large variety of antibodies.

Exercises

1. What is the appearance of poison ivy? Poison ivy (or poison oak) should be demonstrated and drawn. Does its appearance differ in different seasons of the year? Directions for preventing and treating ivy poisoning should be given. Consult encyclopedias and first aid manuals.

2. How do plants and animals protect themselves against their visible foes? Make a list of the weapons and devices used by plants and of those used by animals. Can you give examples other than those mentioned in the text?

Problems for Classroom Discussion

1. What is always one characteristic of an organism that is mimicked by another species?

2. Might there be cases of mimicry in plants? Explain.

3. Do you remember the various protective devices which keep bacteria from entering your nose? Do you see why any condition that leads to mouth breathing, such as adenoids, should be remedied?

4. You read about bee stings, above. Is mud a good remedy for a bee sting? As the insect stings you a break is made in the skin. What organisms might be introduced with the mud? The poison causes redness and swelling. How may the mud be beneficial? What would be a good substitute for the mud?

5. Do red corpuscles serve as scavengers? Why or why not?

6. In some kinds of blood tests the proportion of white corpuscles to red is determined. State one reason for doing this.

7. Do you remember an activity in bacteria that would help them overcome white corpuscles?

8. What experiments would a scientist have to perform to determine that an antibody is specific?

9. Why may it be unwise to expose yourself to infection, even though you have already had the disease?

10. Do you think it a good practice to expose children to diseases such as measles and chicken pox during a mild epidemic? Give reasons for your answer.

11. *Summary.* You have already listed visible means of defense in plants and animals in an exercise. What other principle (important idea) was explained in this problem? Are you ready to explain the means of defense used against bacteria, telling all you read about phagocytes, immunity, and the various kinds of antibodies?

12. *Unit Summary.* Look back to the unit question. What important idea has been growing steadily in your mind as you read this unit? Is man's struggle as keen as that of other animals? What helps man in his struggle? In the last unit you read about prolific reproduction. What bearing does that have on this unit?

Activities for the Junior Biologist

1. Look through Part 1 and find other examples of animals which are protected by the devices mentioned in this problem.

2. Do you know the difference between ordinary sumac and poison sumac in (*a*) habitat, (*b*) appearance of leaves and fruit? Find out and explain to your classmates.

3. If you can obtain the dried rattle of a rattlesnake, attach it to the arm of a buzzer. Connect the buzzer to a dry cell. This will give you approximately the sound of the rattle in life.

4. Make an exhibit of insects for a class museum to show protective coloration and mimicry.

5. If you can obtain pus material from a small pimple, smear a bit of it on a slide and allow it to dry. Then pass the slide through a flame quickly once or twice. (Do not bring the material in direct contact with the flame.) Now cover the dried pus with a dye such as methylene blue, and allow it to stand for two or three minutes. Wash the dye off in running water and examine under the high power of the microscope. You should be able to see phagocytes with engulfed bacteria.

6. Read about Eli Metchnikoff and his discovery of phagocytes. (*Microbe Hunters* by Paul De Kruif.)

7. Make a collection of plant galls. Do the galls found on different plants differ? Why? Cut open galls to find the insect inside.

Good Books to Read

Arnold, A. F., *The Sea-Beach at Ebb-Tide.* Appleton-Century.
Borradaile, L. A., *The Animal and Its Environment.* Frowde (London).
Boulenger, E. G., *Natural History of the Seas.* Appleton-Century.
Campbell, D. H., *Outline of Plant Geography.* Macmillan.
Causey, D., *Uninvited Guests.* Knopf.
Chapman, F. M., *My Tropical Air Castle; Nature Studies in Panama.* Appleton.
Crowder, W., *Dwellers of the Sea and Shore.* Macmillan.
De Kruif, P. H., *Microbe Hunters.* Harcourt, Brace.
Doane, R. W., *Common Pests.* Thomas.
Downing, E. R., *Science in the Service of Health.* Longmans.
Gager, C. S., *The Plant World.* University Society.
Haldane and Huxley, *Animal Biology.* Clarendon Press.
Heald, F. D., *Diseases of Plants.* McGraw-Hill.
Henrici, A. T., *Bacteriology.* Heath.
Jaeger, E. C., *Denizens of the Desert.* Houghton Mifflin.
Jordan and Kellogg, *Animal Forms.* Appleton.
Kendall, A. I., *Civilization and the Microbe.* Houghton Mifflin.
Morgan, A. H., *Field Book of Ponds and Streams.* Putnam.
Needham, J. G., *The Animal World.* University Society.
Reed, W. M. and Bronson, W. S., *The Sea for Sam.* Harcourt, Brace.
Robbins, W. W. and Ramalay, F., *Plants Useful to Man.* Blakiston.
Skene, M., *Biology of Flowering Plants.* Macmillan.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.

UNIT IX. WHAT METHODS DOES MAN USE IN THE STRUGGLE WITH OTHER ORGANISMS?

Problems

1. In What Ways Has Science Taught Man to Fortify His Body against the Bacteria of Disease?
    - *A.* How Does Man Study Bacteria?
    - *B.* How Did the New Techniques Enable Man to Fortify His Body against the Bacteria of Disease?
2. What Methods Does Man Use to Keep Harmful Microorganisms at a Distance?
3. What Measures Are Used by Man to Defend Himself against the Larger Competing Organisms?

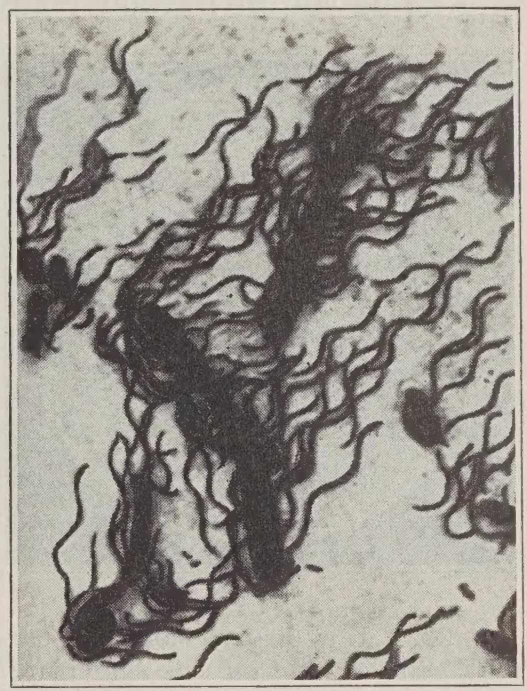
Problem 1*A*. How Does Man Study Bacteria?

Why was progress in studying bacteria necessarily slow in the early days? Anton Van Leeuwenhoek, almost two hundred years ago, saw bacteria among the many wriggling, spinning organisms he studied, but he saw only the larger kinds. Most species of bacteria remained invisible until the compound microscope had been perfected.

But this was not the only reason that little progress was made in studying bacteria. It was difficult for men to experiment with bacteria and learn much about their ways of life until means had been devised for raising them in large numbers in the laboratory. This was often done in test tubes containing broth or soup. Bacteria are still raised or *cultured* in this way. And the broth is called a *culture medium.* When the culture medium is kept in an incubator at a steady temperature that suits the bacteria, they feed, grow, and multiply very rapidly. After this discovery *bacteriology* (the study of bacteria) made great progress. *Exercise 1.*

What was another great advance in bacteriological method? By the time microscopes had been improved and good culture media had been found many scientists had turned their attention to bacteriology. Investigators all over the world were busy trying to develop improved techniques (teck-neeks′ — methods) for studying bacteria. The greatest advances were made by Robert Koch (1843–1910), who began his career as a country doctor in Germany. While he was conscientiously writing prescriptions and visiting his patients he was wondering all the time about the causes of the mysterious diseases he was trying to cure. Every spare moment found him with his microscope or his test tubes of bacteria. He soon realized that before he could get very far in his understanding of disease it was necessary for him to improve his methods of studying bacteria.

One of his first difficulties in studying bacteria was that he often failed to find them when he examined the tissues of a diseased animal under the microscope. Yet he suspected they were present in large numbers on the very slides he was examining so closely. Koch and several other bacteriologists decided at about the same time that if bacteria could be dyed or stained they would show up against any background. Koch experimented with this for many years and finally developed various ways of staining. These staining methods are still being used by scientists, although they have been changed and improved.

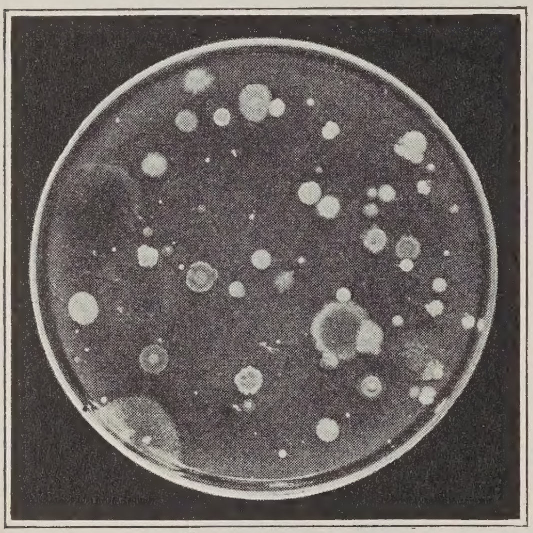


Gen. Biol. Supply House

FIG. 331. These typhoid bacteria can be seen so clearly, even in the photograph, because they were carefully stained after being killed.

How did Koch improve methods of raising bacteria? But Koch encountered another difficulty. The pathogenic bacteria in which he was interested, those he took from the bodies of diseased animals, would not grow in the broth generally used in the laboratory. But after experimenting he found that if he added to his culture medium some fluid taken from an animal's body, such as blood serum or the liquid from the eye, it would serve as food for these bacteria. This was a great step forward, for now scientists could raise pathogenic bacteria outside of the animal's body. That meant that they could have them for study at all times and in as large numbers as they desired. *Exercises 2, 3.*

But when bacteria were taken from an animal's body and raised in a liquid culture medium many different kinds were often found to be living together. The bacteriologist found himself unable to experiment with any one kind because of the large variety. This was a serious stumbling block until Koch devised a method of mixing gelatin with the broth. While it was still liquid he added bacteria to the mixture and poured it into flat glass dishes. As it cooled it hardened, clear and transparent.



Courtesy Brooklyn Bot. Gar.

FIG. 332. How many colonies of bacteria can you find on this agar plate? How many bacteria were introduced? Why are the colonies of different shapes and sizes?

The bacteria which had been introduced were spread over a large surface and each bacterium was likely to settle apart from the others. As each bacterium ate, grew, and reproduced, the new bacteria formed by division were obliged to remain together around the spot where the "parent" had first settled. They were caught in the moist solid mixture; they could not move away even when they possessed structures for locomotion. Some hours later tiny masses of bacteria known as *colonies* thus became visible to the naked eye. These colonies would be dotted over the gelatin, each independent of the other as a rule.

Later, in place of gelatin, scientists began to use dried agar-agar, which comes from a seaweed obtained off the coast of Japan. Like gelatin it dissolves in hot water and jellies or stiffens when it cools. Koch's techniques have been slightly modified in other respects, too.

How did Koch make a "pure culture"? Having shaken the various bacteria apart and forced them to keep their offspring in one spot it was easy for Koch to continue to raise each kind of germ by itself. With a needle he removed some of the bacteria from one colony; many would be caught on the point of a needle but since they all came from one colony, they were, of course, all of the same kind. These bacteria were then transferred to a new agar plate or to a test tube containing broth. Here they multiplied and formed a *pure culture,* that is, a growth of one kind of bacterium. This is a common procedure in all laboratories today. In making the transfer, care must be taken not to mix the bacteria with those that are always likely to be floating in the air or resting on the needle itself. The agar plate or tube of broth must of course be free from bacteria when the transfer is made and must be protected against the entrance of stray bacteria after the transfer has been made. If a culture is to be pure, all bacteria must be excluded except the kind to be grown; everything used must be *sterile* (ster′ill) or free from bacteria. *Exercises 4, 5, 6, 7, 8.*

How may substances be sterilized? Boiling in water, that is, heating to 212° Fahrenheit (or 100° centigrade), is the commonest method of sterilizing substances in the home. But it is not effective enough for the laboratory. Some bacteria are easily killed but others are tough or resistant. These have the power of forming *spores;* that is, they stop taking in food and secrete a thick wall around themselves. Oxidation goes on very slowly and the bacterium may remain in this resting condition for weeks or even months. Killing off a bacterium wrapped in its heavy spore coat is very difficult. To sterilize, or kill off all bacterial life, therefore, one must employ methods which will destroy the resistant spores as well as the active bacteria. Even several hours of boiling are often insufficient to kill the protoplasm within a spore, but scientists have found that when they heat bacteria in steam kept under great pressure the spore coat cannot protect the protoplasm. This method of killing bacteria is used not only in the laboratory but also in the home when a pressure cooker is used in preserving fruits or vegetables. A substance may be sterilized, too, by being heated in steam for an hour on three days in succession.

There is another method of destroying all bacteria, including their spores: it is by using strong chemicals which destroy the protoplasm. Such substances are known as *disinfectants.* Of course, in sterilizing a culture medium disinfectants cannot be employed. If you added a disinfectant to your broth or agar, there could be no growth of those bacteria which you were trying to raise.

How do disinfectants differ from antiseptics? Disinfectants must not be confused with *antiseptics.* A disinfectant kills all protoplasm. An antiseptic does not, as a rule, kill bacteria; it merely produces conditions which are unfavorable so that the bacteria do not increase in numbers. Naturally, since antiseptics cannot kill the bacterial cell they are likely not to be very injurious to the body cells, either. For that reason antiseptics are used on cuts and wounds where they will keep the bacteria from growing and reproducing, yet do little damage to the tissue cells.

Exercises

1. How may bacteria be raised in a liquid culture medium? Heat together in a saucepan 250 cc. (a glass) of water, 2½ grams of salt, 2½ grams of peptone and 2½ grams of Liebig's beef extract. Filter into test tubes, filling them about ⅓ full.* Close each test tube by stuffing a wad of sterile absorbent cotton into the mouth. Put a very small amount of material scraped from the inside of your mouth into each of several tubes. Close them again. Do not open the other tubes. Place all the tubes in a warm place for several days. What do you notice? What may account for the change in the broth? How could you find out?

2. *Demonstration.* To show how staining helps in the study of bacteria. On each of two slides smear a small drop of the broth containing the bacteria. Permit the slides to dry. Then pass them through a flame rapidly three times with the side of the slide that contains the bacteria uppermost. Cover the material on one slide with some dye like methylene blue or gentian violet and allow it to stand for two minutes. Wash the dye off with water and examine the slide under the oil immersion lens of the microscope. Compare the unstained slide with the stained one. What do you note?

3. What kinds of bacteria are found in the broth prepared in Exercise 1? Examine the stained slide that you prepared in Exercise 2. How many forms of bacteria do you see? The rod-shaped forms are bacilli, the spherical forms are cocci, and the corkscrew-shaped ones are spirilla. Which of these kinds seems to be most abundant?

---

* These tubes of broth should be thoroughly heated (sterilized) but results can be obtained without doing this.

4. How may petri dishes with nutrient agar be prepared? Heat together the ingredients mentioned in Exercise 1 (using four times as much of each) and add 10 grams of agar. Put in baking soda until red litmus paper is turned blue by the mixture. When the agar is dissolved, filter the mixture through thick absorbent cotton lining a funnel. Warm the cotton and funnel before they are used. Why? Allow the filtered substance to flow into a glass flask. Plug the mouth of the flask with a wad of sterile absorbent cotton. Why is the plug used? Why is a cotton plug used instead of a rubber stopper? If you wish to use this nutrient agar for studying special kinds of bacteria or if you wish to keep it, what must you do to the agar in the flask? Why? If you wish to pour the agar into plates or petri dishes, what should you do to the petri dishes in advance? When you are ready to transfer the sterile agar into sterile petri dishes, you must heat the flask to liquefy the agar mixture and then pour it in such a way that as few bacteria as possible will have a chance to enter during the pouring. What precautions would you suggest? Consult with your teacher to make sure that you have thought of all possible precautions.

5. What can be learned about bacteria grown on agar plates? Pour two or three drops of the broth containing bacteria into a sterile agar plate and spread the liquid well over the surface. Close the petri dish and set it aside in a warm place (about 80° F.). Examine every morning and evening. How long does it take before you see bacteria on the agar? Why can the bacteria now be seen? Each colony contains millions of bacteria. What does this tell about their rate of reproduction? What are some of the differences among the colonies? Of what use might a knowledge of these differences be to a bacteriologist?

6. Where are bacteria found? Expose a number of sterile petri dishes containing sterile agar to the air in your classroom, in the school corridor and playground and in other places for several minutes. In others, place various objects; such as chalk dust, dust, food, saliva, and so on. Label each of the dishes and put them away in a warm place for a few days. What do you find? How can you be sure that the bacteria came from the various objects or places to which the petri dishes had been exposed?

7. Devise and perform an experiment to find out the relative number of bacteria in your classroom and in your home. What will you need for your experiment?

8. *Demonstration.* To show how a pure culture of some striking colony is made. Pure cultures are generally grown on agar *slants.* To make an agar slant, pour some sterile agar into a sterile test tube and plug it with a wad of absorbent cotton. Then place the test tube in a tilted position at an angle of about 30 degrees until the agar hardens. Before transferring the bacteria to the slant, what must you be careful to do with the needle you employ? Would you recommend heat or disinfectants? Why? Holding the needle in the flame until it is red hot and then allowing it to cool for a moment before applying it to the colony of bacteria will prove successful. Why is a test tube better than a petri dish for making a pure culture?

Problems for Classroom Discussion

1. Can you explain why broth makes better food for some bacteria than soil?

2. Why do colonies form on an agar medium but not in broth?

3. If ten colonies form in a sterile petri dish how many bacteria must have been introduced into the dish?

4. In making a pure culture what can you do to make sure that the needle used for transferring will be free from bacteria?

5. What other precautions could you take to keep your pure culture from becoming contaminated?

6. Why should heating in steam for an hour on three successive days be better than heating for three hours in a stretch?

7. Compare a bacterial spore with a mold spore. In what process is a mold spore formed?

8. *Summary.* Before man could learn to protect himself against the bacteria of disease what facts did he need to know? Can you explain, or still better demonstrate, each of the techniques perfected by Robert Koch and other bacteriologists?

Activities for the Junior Biologist

1. You can use small wedges of potato as a medium for the growth of bacteria. Boil an unpeeled potato and cut out wedges with a sterile knife. Place the wedges of potato in sterile test tubes. If you wish to use petri dishes use large slices of potato instead of wedges.

2. How might you find out whether or not there are bacteria on a door knob or on a pencil? What else might you test?

3. To what extent is the growth of bacteria affected by temperature? Devise an experiment. Discuss it with the class before trying it.

4. How valuable is iodine or any other antiseptic that you are in the habit of putting on your cuts and scratches? Remember that an antiseptic is supposed to hinder the growth of bacteria. Can you devise an experiment, using sterile agar plates, to test various common antiseptics? Keep accurate notes of all you do and observe.

Problem 1*B*. How Did the New Techniques Enable Man to Fortify His Body against the Bacteria of Disease?

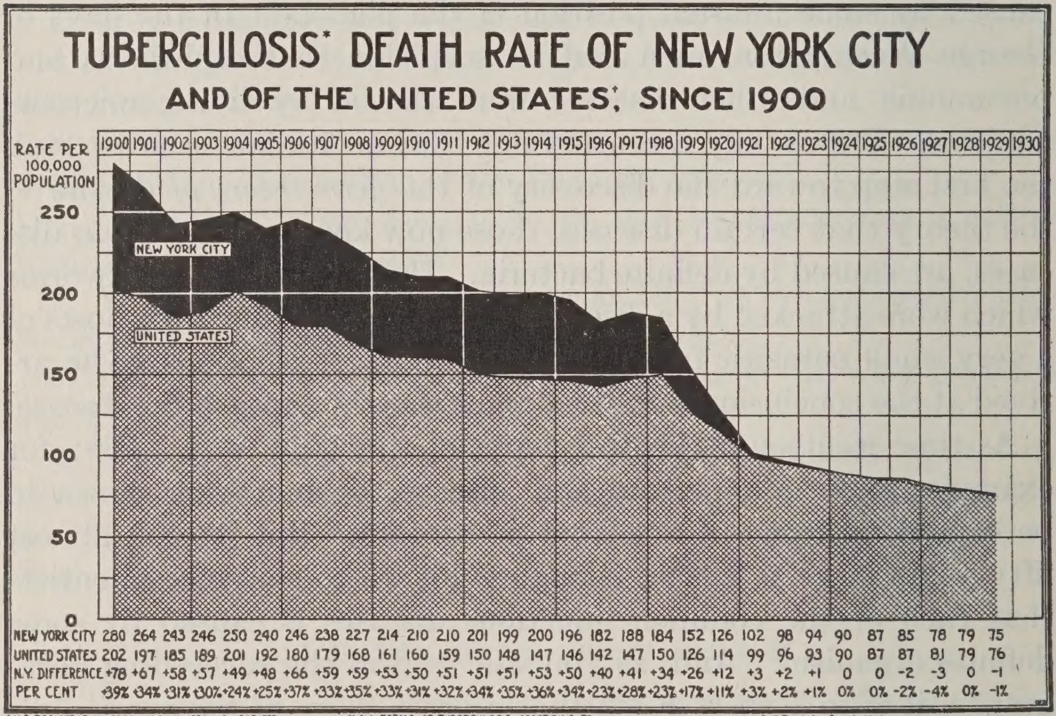
What led biologists to believe diseases might be caused by bacteria? You are all so accustomed to the idea that certain diseases are caused by the entrance of microorganisms (microscopic organisms) into the body that you forget that man has not always known this. At the time when the early settlers came to this country medical students were still being taught that disease was caused by some unusual position of the planets! In the days of George Washington, men had no suspicion that diphtheria and pneumonia and other diseases were caused by living microorganisms. It was only a century ago that an Italian scientist took the first step toward the discovery of the *germ theory of disease* — the theory that certain diseases, those now known as *infectious* diseases, are caused by definite bacteria. He noted that all silkworms which were attacked by a disease common at the time were hosts of a very small parasitic fungus. There were no exceptions, so he arrived at the conclusion that the fungus was the cause of the disease.

As time went on other discoveries of this kind were made; for example, some unimportant skin diseases of man were shown to be caused by fungi of one kind or another. But it took almost fifty years more to collect enough evidence to convince scientists that each of the common infectious diseases is caused by some definite organism. And, as you will read in the succeeding paragraphs, it is to Robert Koch that a great share of the credit falls for the establishment of the germ theory of disease.

What were Koch's first great achievements? About 1875, suspecting the part played by bacteria in disease, Koch turned to a study of the cause of anthrax. Although it did not often attack man, anthrax was a common disease of sheep and cattle that resulted in enormous loss of money. Earlier, another bacteriologist had declared that a specific germ caused the disease but he had not produced convincing evidence. To check this belief took years of patient investigation and experimentation by Koch and other men working in bacteriological laboratories in various countries. Koch's persistent efforts were crowned with success at about the same time that several other scientists also produced the proof that one specific bacillus caused anthrax.

Some years later, in an investigation that won the admiration of bacteriologists all over the world, Koch proved that one particular bacillus was the cause of tuberculosis. Koch thus not only made possible the beginning of man's increasingly successful campaign against tuberculosis, but he helped to establish the germ theory of disease.

How has the discovery of the germ of tuberculosis helped man to conquer the disease? To be sure, the discovery of the tuberculosis germ has not enabled anyone to find a cure for the disease but it has pointed the way to methods of prevention. Physicians can now look for the germ when they first suspect tuberculosis and thus often discover the disease in its early stages. The common type of tuberculosis of the lungs develops so slowly that if it is detected before the germ has become too well established the body, if given rest and good food, can cure itself. Then, too, knowing that the disease is caused by a germ, people can take precautions to keep the germ from entering. Thus the disease


TUBERCULOSIS* DEATH RATE OF NEW YORK CITY
AND OF THE UNITED STATES†, SINCE 1900

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
NEW YORK CITY	280	264	243	246	250	240	246	238	227	214	210	210	201	199	200
UNITED STATES	202	197	185	189	201	192	180	179	168	161	160	159	150	148	147
N.Y. DIFFERENCE	+78	+67	+58	+57	+49	+48	+66	+59	+59	+53	+50	+51	+51	+51	+53
PER CENT	+39%	+34%	+31%	+30%	+24%	+25%	+37%	+33%	+35%	+33%	+31%	+32%	+34%	+35%	+36%

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
NEW YORK CITY	196	182	188	184	152	126	102	98	94	90	87	85	78	79	75	
UNITED STATES	146	142	147	150	126	114	99	96	93	90	87	87	81	79	76	
N.Y. DIFFERENCE	+50	+40	+41	+34	+26	+12	+3	+2	+1	0	0	-2	-3	0	-1	
PER CENT	+34%	+23%	+28%	+23%	+17%	+11%	+3%	+2%	+1%	0%	0%	-2%	-4%	0%	-1%	

† U.S. REGISTRATION AREA WHICH IN 1920 INCLUDED 82% OF THE POPULATION OR 87,486,713 INHABITANTS.

* ALL FORMS OF TUBERCULOSIS ACCORDING TO MORTALITY STATISTICS U.S. CENSUS BUREAU.

G.J. Drolet, Statistician
NEW YORK TUBERCULOSIS AND HEALTH ASSOCIATION, Inc.

FIG. 333. Compare the tuberculosis death rates of New York City and the country as a whole. Can you explain the changes in death rates that have occurred? What might explain the improvement in New York City?

which is known as the great "white plague" is one which is well under control in some communities.

How did Koch convince himself that tuberculosis cannot occur without the entrance into the body of some specific germ? On examining the bodies of animals which had died of tuberculosis Koch found many kinds of bacteria, but one type seemed always to be present. Unfortunately, he was not sure that those that seemed to him to be of one type were really members of the same species. Perhaps there were several kinds of bacteria that looked so much alike that his microscope could not distinguish among them. Koch solved this problem by using a new staining technique; he was able to develop a special method of staining which dyed one species but not the others of the same shape and general appearance. The bacterium for which the stain was prepared was the one Koch suspected of causing tuberculosis. He had found it by the millions in every tubercular animal; after the new stain was used he was sure that he was not being deceived by similarity in shape.

Although he always found this type of germ in animals which suffered from tuberculosis Koch was not yet convinced that this bacterium *caused* the disease; perhaps it merely accompanied the disease. To settle this point, Koch grew the germ on his solid culture media. He prepared many pure cultures of it. Then he injected some of these bacteria into an animal which he had kept under observation for some time and which he knew to be healthy. The animal contracted a disease with the typical symptoms of tuberculosis and died.

Even then Koch was not fully convinced. He therefore stained the germs which he found in this dead experimental animal. It was not until he was sure that the germs were the same as those he had grown on his culture media that he felt justified in saying that tuberculosis is caused by the tuberculosis germ. Of course, Koch repeated this experiment many times before he presented his proof to the world.

It was convincing evidence of the so-called germ theory of disease. Since Koch's time so much more evidence has piled up that no person questions the truth of the statement that there are diseases caused by germs. *Exercises 1, 2.*

How did Louis Pasteur arrive at the germ theory of disease? No scientist can work out every step of a problem without direct or indirect help from others. Had Koch failed to read the scientific journals of his day to find out what other scientists were doing, had other bacteriologists not taken an interest in his work and discussed it with him, he would never have been successful in establishing the germ theory of disease. There were many men working along these same lines at this time. Among them was Louis Pasteur (1822–1895), who probably deserves as much credit as Koch for proving that certain diseases are caused by the growth of a particular germ within the body.

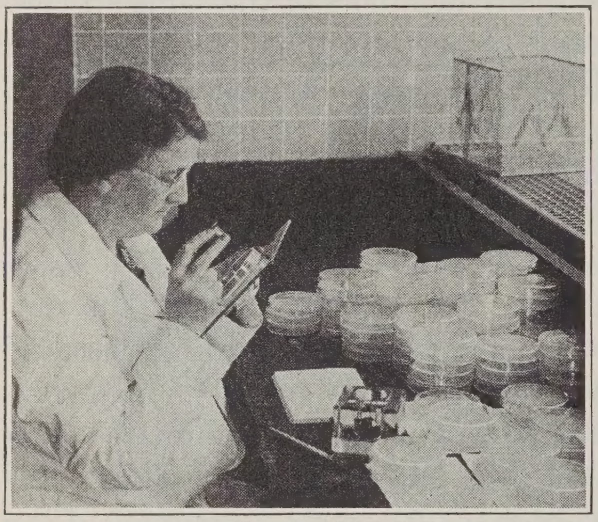

Courtesy N.Y.C. Board of Health

FIG. 334. A Board of Health worker examining a tuberculosis smear. How does this work help to decrease the tuberculosis death rate?

Louis Pasteur, the son of a French tanner, began as a chemist. He worked long hours every day in his chemical laboratory with feverish interest trying to find why milk sours and what goes on when wines and beers ferment. Soon he was convinced, as the result of his experiments, that milk does not sour, nor grapes ferment, unless some microorganism is present in the liquid to bring about the change. And every time the beer or wine sours or spoils it is because some microorganism of a different species happens in. Hand in hand with this research went his experiments which helped to disprove finally the old belief in spontaneous generation. Thus Pasteur, although a chemist, was becoming well acquainted with bacteria and their ways of life. And the suspicion now came to him that disease in the body is similar to the changes which occurred in his tubes of wines and beers. He therefore turned to a study of diseases in animals. He suspected that bacteria, no doubt of different species from those he had been raising in his laboratory, must be the cause. Before he could solve this age-old problem of disease and find experimental evidence for this theory Koch published his discoveries.

How did Pasteur build on the germ theory of disease? When the germ theory had been established, Pasteur devoted his attention to the animal's power to protect itself, its immunity. With the help of his assistants he raised pathogenic bacteria of many kinds in his laboratory. Among others he raised pure cultures of the bacteria which cause cholera (coll′er-a) in chickens. One day he discovered, largely by accident, that when he kept these cultures for some time, the bacteria seemed to become weaker. He concluded this because he noticed that when such cultures were injected into healthy birds, they did not become violently ill as they did from the injection of fresh cultures; they showed no symptoms of the disease or at most had only a mild attack. It was a lucky accident which led to this discovery but Pasteur was wise enough to recognize its importance. He saw how this discovery might be used in a practical way. Why not, he reasoned, cultivate such weakened germs in large numbers and *inoculate* (in-ok′you-late — inject) them into healthy chickens? After having a mild case of the disease the chickens might be immune. They could then resist the disease in case an epidemic of chicken cholera should occur. He tried this and it worked. When next an epidemic of this disease occurred all the inoculated birds were spared; they seemed to be immune as Pasteur had hoped. In those days, the various antibodies had not yet been recognized. In fact, Pasteur died before these discoveries were made, but he knew that in some way the animal must be responding to the bacteria so that it did not acquire the disease.

Working on this theory he now turned his attention to anthrax. Koch had shown how to raise the bacteria in pure culture. Instead of letting them grow old in the culture medium, Pasteur tried something new. He subjected them to a high temperature (108° F.) for some days. This he found, on experimentation, weakened them successfully, for when he injected them into healthy sheep the animals came down with anthrax but in a mild form. When the sheep had recovered entirely from that attack he inoculated them with the most virulent (strongest) anthrax germs he could find. Most of the animals resisted the disease completely; just a few had a slight attack of anthrax. Pasteur was building on the germ theory of disease; he was developing methods of giving immunity. This was not only of great practical value but helped to establish the truth of the germ theory of disease.

How did Pasteur apply his theory to the saving of human lives? Having been so successful in immunizing animals against two diseases Pasteur attempted to apply the same principle to a disease which was one of the most horrible that afflicted human beings — hydrophobia, or rabies (ray′bees), as it is now more often called. Formerly, rabies was a common disease among dogs and from them it frequently spread to human beings. It was always fatal. After much experimentation Pasteur succeeded in weakening the organism which caused rabies. The strange thing is that he never was able to find the germ and to this day it has not been seen. It is believed now to be one of the *filterable viruses* (vy′rus-es), one of the organisms too small to be seen with the microscope. But Pasteur had learned that the organism, whatever it might be and however it might look, settled in the spinal cord and brain. So he cut out the spinal cord of a rabbit which had died of rabies and because he had found that drying weakened the unknown germ (virus) he hung the cord up to dry in a bottle with chemicals that would draw out the moisture. Then he ground the cord into a pulp so that he could more easily work with it. Since the rabies organism seems to be so very powerful he allowed the spinal cord to dry for many days before he injected any of it into a healthy animal. He hoped that when the much weakened virus was used the cells of the animal would react by building up the animal's resistance. The next day Pasteur injected some more of the virus but this time he took it from a cord that had been drying a shorter time; that is, the virus was not as much weakened as that used for the first injection. He continued this procedure for fourteen days, each time using stronger and stronger virus. After each injection the body must have made more and more antibodies, for at the end of the treatment the animal proved to be immune to the disease.

These experiments of Pasteur were performed on dogs. They had all been successful and the theory underlying them seemed sound but Pasteur still hesitated to try out his weakened virus on human beings. One day he was obliged to do so. A nine-year-old boy who had been bitten by a mad dog was brought to his laboratory. The parents pleaded with Pasteur to use his treatment on the child. Still Pasteur hesitated, for this case was different from those he had experimented with before. In his laboratory his dogs were inoculated with the virus before they had been bitten by a rabid animal; now he was asked to inject virus into the child which had already been infected. But knowing that the disease comes on very slowly, sometimes many weeks after the bite, he thought that possibly his inoculation could take effect before the disease reached the brain. Knowing too that without treatment the child could not possibly recover, Pasteur finally yielded to the persuasion of the parents. After fourteen days of treatment the child left the hospital; rabies never developed. The child had been saved.

This boy was the first human being who was spared the most horrible of deaths by rabies. Now, however small the bite of the dog, if the skin is broken at any point, inoculations against rabies are given. Of course, this precaution need not be taken if the dog is examined by the health officer and declared healthy.

Why is it often said that Pasteur saved more lives than Napoleon took in all his wars? It is not that Pasteur saved so many people from death by rabies, for rabies was never a widespread disease. It is because he established a new principle: that of immunizing the body against a specific disease. He had shown how the body can be made to protect itself by the injection of weakened germs. This fundamental principle of immunization could be applied to other diseases; it could be modified in various ways. Thus Pasteur's work paved the way for further great discoveries.

What great discovery came as the result of the work of Koch and Pasteur? Sir Joseph Lister practiced surgery in Scotland in the middle of the last century. He was considered highly successful although, like other physicians, he had to use hot tar or red hot irons to prevent pus formation after he had cut off a hand or an arm. Of course, he attempted an abdominal operation only when it was altogether unavoidable, for in such operations either blood poisoning or gangrene almost always followed. That is what surgery meant until about the year 1860.

Surgeons had concluded that the tissues always undergo changes when exposed to the oxygen of the air. Lister, however, and some other scientists, among them an Austrian doctor by the name of Semmelweis, wondered whether the blood poisoning that accompanied so many operations might be caused by the activity of bacteria in the wound. The test, of course, was to kill the bacteria and watch the effect on the wound. Lister used a strong disinfectant, carbolic acid, and dipped his hands and instruments into it before he went to the operating table; he sprayed the body of the patient throughout the operation; then he soaked gauze in carbolic acid and covered the wound with it. His success was immediate; wounds did not develop pus and the number of deaths after operation decreased considerably.

But Lister was not wholly satisfied with his method, for the carbolic acid which so successfully killed the bacteria also injured the tissue cells and the wound healed slowly or not at all. Lister then tried the following: instead of sterilizing the wound after the bacteria had settled in it, he made it impossible for bacteria ever to get in. He sterilized his instruments with boiling water and operated in a room which was as nearly sterile as he could make it. Instead of soaking the wound in disinfectant the skin was made sterile before the operation was begun. In other words, Lister developed what is called *aseptic* surgery instead of *antiseptic* surgery. Thereafter, wounds healed rapidly and blood poisoning was the exception instead of the rule. Since Lister's day many improvements have been made in the construction of the operating room and in methods of keeping everything sterile. We owe a great debt of gratitude to Joseph Lister but his discovery would not have been possible had it not been for the painstaking work of Robert Koch and Louis Pasteur and their many co-workers, all of whom together developed and established the germ theory of disease.

How did Edward Jenner wipe out one of the scourges of olden times? If you have ever had a smallpox vaccination that "took" you will remember the intense itching in that spot. You were having a very mild attack of smallpox on one small area of your body. In a true case of smallpox the patient has spots all over his body that itch and get sore, and frequently leave deep pits or "pocks" after they heal. You do not often see people with faces disfigured with pock marks; you rarely hear of anyone being taken to the hospital with a case of smallpox. It is a disease that, in our part of the world, has been almost wiped out. Yet up to about 1800 there were not many persons who escaped the disease with all its torture.

It was Edward Jenner who was largely responsible for the change. In about 1790 Jenner followed up some interesting observations and tests that had been made by farmers. Cows suffered from a disease that resembled smallpox; in fact it was called cowpox. The dairymaids that milked these diseased cows frequently came down with a mild disease something like smallpox. Now people had noticed that when the next epidemic of smallpox came and everyone else on the farm fell ill these dairymaids were spared. Jenner, following the methods of a few courageous men who had tried this before, scraped some of the material from one of the sores or pustules of a cow that was suffering from cowpox and rubbed it into a scratch on a boy's arm. The boy was only mildly ill; later he resisted smallpox even when directly exposed to it. Jenner said he *vaccinated* the boy because he took material from a *vaccus*, the Latin word for cattle. And the material he used was called *vaccine* (vak-seen′).

Vaccination became fashionable in England; people were willing to try anything to escape smallpox! The practice spread to the Continent. Jenner was called to the royal courts of Europe; he was honored and fêted by kings and adored by the common people. Although vaccination is not yet practiced in every country, Jenner showed that smallpox may be prevented. *Exercises 3, 4.*

How can you be given immunity without working for it? When you are given the Pasteur treatment against rabies or when you are vaccinated against smallpox it is the cells of your body which work to make you immune. You are not conscious of it, but after such inoculation innumerable cells within you are at work twenty-four hours a day making antibodies. Thus you become well fortified with antibodies against rabies and smallpox. The type of immunity acquired in this way is called *active immunity*, since your body cells are active in building up defenses.

There is still another way of getting antibodies, an easier way for your cells. Scientists now know how to take antibodies from some animal that has more than it needs and inject them directly into the human body. Almost fifty years ago one of Koch's pupils, Emil von Behring, tried this. He immunized a horse against diphtheria by using Pasteur's method of building up active immunity in the animal. He then took the antibodies from the horse and injected them, all ready made, into a person. By this method, within a few hours, the human body can be fully armed against diphtheria. Von Behring used the treatment mostly to *cure* children after they showed symptoms of the disease; but he also injected the antibodies into a child that had been exposed to the disease but had not yet been taken ill. In each case he was successful. The immunity that is thus acquired is known as *passive immunity,* since the cells remain inactive or passive. Such passive immunity is obtained immediately but lasts only two or three weeks.

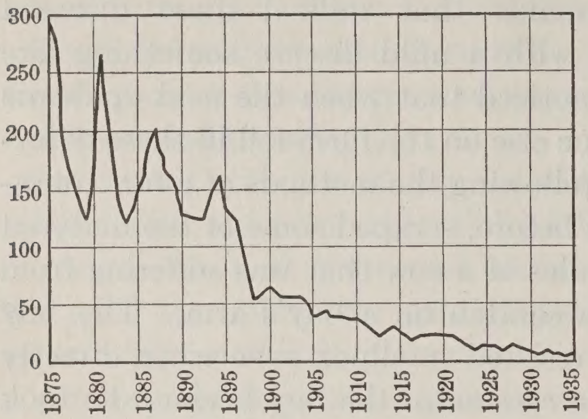
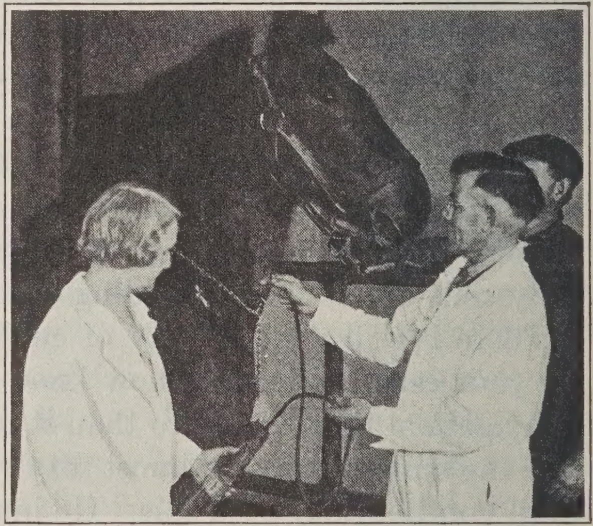


Fig. 335. Death rate from diphtheria per 100,000 people in New York City. What was the rate 50 years ago? What is it now? Since which year has there been a steady decrease? Why? (*Adapted from Bolduan's Public Health and Hygiene, 1936. Courtesy W. B. Saunders Company.*)

How is diphtheria antitoxin prepared? If the physician wants diphtheria antitoxin some animal like the horse must go through the work of acquiring an active immunity against diphtheria. The horse's cells must make antitoxin in response to the diphtheria toxin. Nowadays, instead of introducing germs into the animal, it has been found safer and more practical to inject diphtheria *toxin.* Scientists now raise the diphtheria germs in broth, filter out the bacteria, and collect the toxin. Then they inject the toxin into the animal. Naturally a very, very small amount of toxin is used for the first inoculation. Every five or six days over a period of several months the horse is inoculated again with an increasingly stronger dose. At the end of this time there are large quantities of antitoxin against diphtheria circulating in the horse's blood.



Courtesy W.P.A. & N.Y.C. Bd. of Health

Fig. 336. Bleeding a horse for antitoxin. Why is this horse able to supply antitoxin?

Bleeding the horse; clotting the blood; refining and preparing the serum with its contained antitoxin; testing it out on some laboratory animal; and finally bottling it are the steps in a long and costly process, for all these operations must be performed with the greatest care and accuracy. Since the antitoxin is prepared by skilled laboratory workers you may be sure that it is safe for use.

By what other method may you borrow antibodies? Since most germs do not give off their toxins, true antitoxins cannot be developed for most other diseases in the way discovered by von Behring for diphtheria. But within recent years it has been found that the various antibodies which a person makes in recovering from a disease can sometimes be used to help someone else. For example, the child who develops measles is sometimes given "immune serum" obtained from some adult who has had the disease, perhaps many years earlier.

When will diphtheria become a disease of the past? Von Behring's discovery of antitoxin has saved many children from death by diphtheria. But this discovery has not been as successful in wiping out diphtheria as vaccination has been in wiping out smallpox. You read above that the antitoxin made by the horse and inoculated into a person remains in the circulation only a few weeks; then the person is again susceptible to the disease. Realizing this great drawback, scientists attempted to discover a method of building up active immunity against diphtheria. Dr. Bela Schick, an Austrian physician now living in the United States, succeeded in this. He injected some diphtheria toxin into the arm of the healthy person. For safety's sake he used some antitoxin with the toxin in his experiments. The mixture is called "toxin-antitoxin." He started with a weak dose and gave the cells time to make their antitoxin. Then he gave a second stronger inoculation, and after a while a third. The active immunity which is developed lasts for many years in most people.

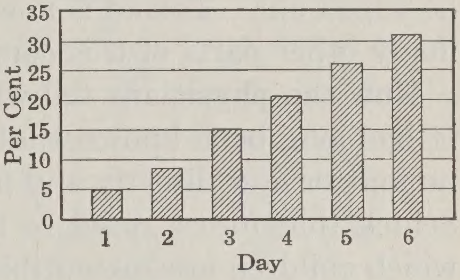


FIG. 337. If diphtheria antitoxin is given on the first day of disease, the per cent of deaths is very small. If treatment is delayed, what is the result? (*Adapted from Bolduan's Public Health and Hygiene, 1936. Courtesy W. B. Saunders Company.*)

This was a great discovery and Dr. William H. Park, then

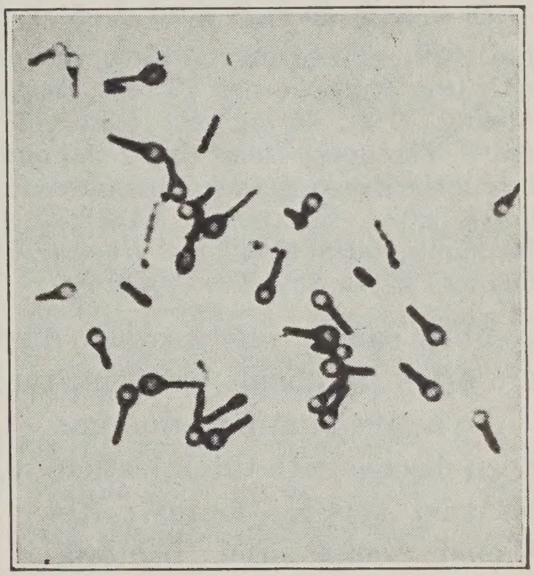
Director of Laboratories of the New York City Department of Health, quickly recognized its importance. Many years earlier, when von Behring discovered antitoxin, Dr. Park, alert to new discoveries, had introduced its use in the city of New York. As soon as he was convinced that toxin-antitoxin was safe and effective, Dr. Park again took active steps to spread its use. Immunization was offered to children in the public schools and parents were urged in every way possible to make use of this opportunity.

After some years another scientist improved on Dr. Schick's original method; he injected a material called *toxoid* (tox′oyd), which consists of specially treated toxin. Only one injection of toxoid is necessary. When every child who needs immunity against diphtheria has been inoculated with toxoid the disease will be wiped out. Toxoid is now used in New York City as well as in many other parts of this country.

How can physicians tell which children need to be immunized? It has long been known that some children fail to get diphtheria no matter how directly and how often they are exposed to it. Dr. Schick therefore wanted to find a way of discovering in advance which children are susceptible (can get the disease) and in need of immunization, and which are not. He devised a simple test, now known as the "Schick test." A very small amount of toxin is injected into the skin of the arm. After about twenty-four hours a doctor can tell from the appearance of the region whether or not the person has enough antitoxin of his own and is naturally immune. If a peculiar red region appears the results are "positive"; that is, the child is susceptible. In that case the doctor recommends immunization with toxoid. If the results are negative then the child can be spared the inconvenience and expense of immunization.

Scientists have done all that can be done to stamp out diphtheria. It now rests with us to make use of their discoveries. When the community decides to test every child to find out whether it is susceptible and then immunizes every child that needs it, diphtheria will become a disease of the past. Immunization is a safe and cheap insurance against diphtheria. And at the same time it helps to protect others in the community. For the fewer susceptible people there are in whom the germ can settle and multiply, the less widely can the disease spread.

How can you insure yourself against tetanus ("lockjaw")? Until recently tetanus (tet'an-us), like rabies, meant certain death. The germ that causes the disease, unlike most other pathogenic bacteria, can form a spore. In this form it can live for a long time without the warmth and food of the animal's body. It is now known that tetanus spores may rest in the soil; they are common in soil which has been long under cultivation, particularly if it has been fertilized with horse manure. The reason for this is clear. The germ lives in the horse and other animals. Having entered through the mouth, it settles in the digestive tract without giving any symptoms of the disease. Thus the germs keep leaving the animal's body in large numbers with the excretions. Once out of the body they form spores in the soil. Other horses, in grazing, swallow some of the spores. In the digestive tract the bacteria have an opportunity to become active and multiply. Thus the bacilli become plentiful in certain soils.



Courtesy Am. Mus. Nat. Hist.

FIG. 338. The bacillus that causes tetanus (lockjaw) forms a spore at one end of the cell.

When any soil, or an object that has been in contact with the soil, gets into a wound there is a good chance that tetanus spores will enter with it. Entering through a break in the skin and not through the mouth, the germs show great virulence whether in man or horse. They form toxins which spread through the system, reach the brain, and cause severe contraction of the muscles (lockjaw). As in the case of diphtheria, if antitoxin is given promptly the disease can be prevented. In all accidents which involve deep wounds it is wise to have a prompt inoculation of tetanus antitoxin. *Exercise 5.*

How was typhoid conquered? Typhoid fever is another disease which has been largely conquered by science. The bacterium enters with food or drink and settles in the digestive tract; it not only causes a general illness but often damages the intestine. The germs

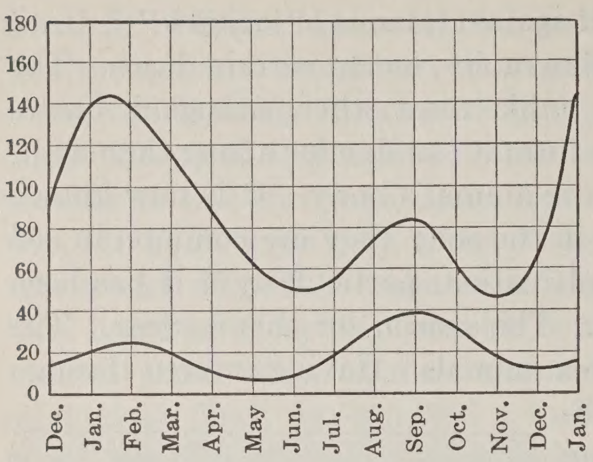
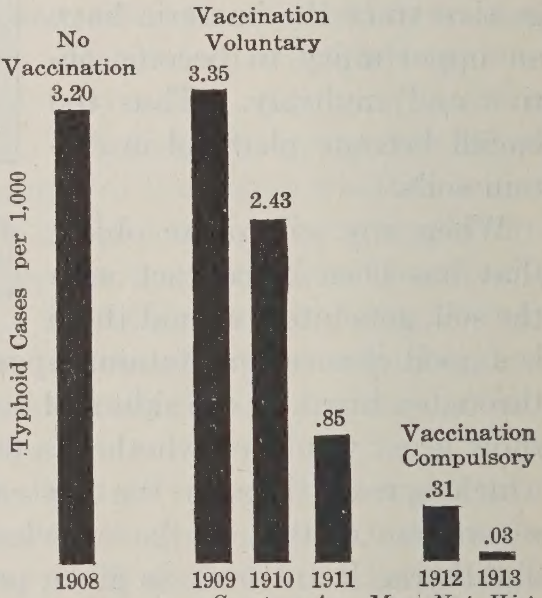


FIG. 339. These curves show the death rate from typhoid per 100,000 people in Albany, N.Y., during each month of the year. The upper curve shows the number before the drinking water was filtered; the lower after filtration. (*Adapted from Bolduan's Public Health and Hygiene, 1936. Courtesy W. B. Saunders Company.*)

keep passing out with the excretions so that they are eventually found wherever the sewage goes, in the soil or in streams and lakes. Water draining through the soil may carry the germs long distances to wells or into larger bodies of water. In this fashion one case of typhoid fever in a community where the drinking water is not properly controlled may start an epidemic. In army camps particularly, but to a lesser degree in all summer camps, where sewage disposal and control of water supply are often a difficult problem, typhoid has always been a danger.

An active immunization has been discovered: the injection of dead typhoid germs. Although dead, the bacteria stimulate the cells to make antibodies. Immunity lasts only a few years so that the inoculation must be repeated if the person is likely to be exposed to the germ later.

In what ways has man learned to fortify his body against pathogenic bacteria? Before man could learn how to protect himself it was necessary for him to develop techniques for studying bacteria. These included not only the improvement of the microscope, but also the staining of bacteria so that they might be distinguished one from the other.



Courtesy Am. Mus. Nat. Hist.

FIG. 340. This shows the number of typhoid cases in the American army from 1908 to 1913. What conclusion can you draw?

They included, too, the raising of bacteria in the laboratory on special culture media, and the making of pure cultures. With these techniques mastered it became possible for Robert Koch and other bacteriologists to develop the germ theory of disease and to prove that a specific germ caused anthrax, and, later, for Koch to find the germ that caused tuberculosis.

Then came rapid progress in fortifying the body against pathogenic bacteria. Jenner had long before this time discovered vaccination against smallpox, without, however, understanding the principle of vaccination. It was Pasteur who, toward the close of the last century, led in the development of the theory of active immunization. He conferred immunity upon an animal by injecting weakened germs. He applied the principle in the case of three diseases, and paved the way for further discoveries. Other scientists discovered how to give active immunity against diphtheria and typhoid fever. Lister, following in the footsteps of Pasteur, developed antiseptic and then aseptic surgery. But in the meantime research was progressing along quite different lines. Passive immunization was discovered; it has made possible treatments for several diseases.

It is not much more than half a century since Koch and his coworkers were developing the first simple techniques. Within that short space of time some of the most dreaded diseases have come almost completely under man's control.

Exercises

1. What methods should be used to prove that a particular germ causes a particular disease? Look back over the preceding paragraph and write down the four distinct steps which Koch considered necessary as proof that a disease is caused by a particular germ. These four steps in his proof are known as Koch's four postulates.

2. Why were scientists slow to accept the germ theory of disease? If the germ theory were a totally new theory to you, would you be convinced of it after you had seen a demonstration such as described in the text? If not, why not? Could you omit any of the steps and still be convinced? If so, which?

3. Can you explain why in Jenner's day severe illness frequently resulted from vaccination? Explain how, even now, there might be trouble as the result of vaccination. State how it can be avoided.

4. If the health records of a large city in which vaccination of school children is required show that in the years from 1930 to 1935 not one case of smallpox occurred but that there were three deaths following vaccination would you consider that a good argument against vaccination? Explain.

5. How is tetanus antitoxin prepared? List all the steps which must be taken if the antitoxin is to be safe for use. (The horse is used.)

Problems for Classroom Discussion

1. You read that all silkworms attacked by a disease were hosts of a parasitic fungus. Are you justified, therefore, in concluding that the fungus is the cause of the disease? Why or why not?

2. What qualities of a great scientist did Koch show?

3. Centuries ago the great English chemist Robert Boyle said that the man who found the cause of fermentation would also discover the cause of many diseases. How much truth was there in this prediction?

4. Who was a greater scientist, Koch or Pasteur? Present reasons.

5. Why has Pasteur become so famous while Koch is little known to many people?

6. What was the underlying idea of immunization discovered by Pasteur?

7. In what ways are Lister's and Pasteur's ideas applied in the home today?

8. List the steps you would take to prevent infection in a wound. Give your reason for each step.

9. Pasteur showed courage. Can you give other examples of a scientist showing courage?

10. A friend of yours has just returned from the hospital after an appendicitis operation. List all the scientists, past and present, whom he has to thank for his safe recovery. Explain.

11. Give the scientific explanation for the results that Jenner got. Note the dates of Jenner's and Pasteur's immunizations. Why is Jenner given so much less credit than Pasteur?

12. How can you explain the fact that oysters, celery, and lettuce can be responsible for typhoid fever?

13. Typhoid germs cannot form spores. What advice would you offer to people living in a community where there had been a case of typhoid?

14. *Summary.* This problem affords a clear example of the fact that scientists build upon the work of their predecessors. Show how Koch's improvements in technique and Pasteur's early discoveries were the foundation for later work. Can you list the diseases against which man fortifies his body and in each case explain how he does it?

Activities for the Junior Biologist

1. Make a report to the class on early theories of disease.

2. Report on the life and work of Robert Koch, Pasteur, Lister, and Jenner. Have your class secretary write to the Metropolitan Life Insurance Company, New York City, for biographies of scientists.

3. Report to your class on Edward Livingston Trudeau and his treatment for tuberculosis.

4. Visit a hospital laboratory to find out what hospitals do in the fight against disease.

5. Report on the antivaccination movement in the United States. If possible, quote arguments used by antivaccinationists to see whether they have good scientific reasons for their statements.

6. Prepare a book of clippings describing recent discoveries in the field of infectious disease.

Problem 2. What Methods Does Man Use to Keep Harmful Microorganisms at a Distance?

In what various ways may microorganisms be harmful? If you put your mind to it you could probably name a dozen different diseases caused by microorganisms. Bacteriologists have identified scores of microorganisms which get into the body and cause trouble of one kind or another. But there are many other microorganisms which are harmful to man in a very different way. There are those that are man's rivals; they eat his food. That in itself would not be so bad, for though very numerous their appetites are necessarily small. But in eating man's food they cause changes in it; they give it tastes and odors which are unpleasant. The process is called *decay.* Thus long before bacteria can have eaten your food they make it undesirable for use, for man does not want food in which decay has gone too far even though it might not hurt him to eat it. Man must constantly guard his food against decay.

By what methods does man keep his foods from spoiling? Long before man knew that decay of food is caused by bacteria, ways of preserving foods had been discovered and were in common use. The pioneers who penetrated the American wilderness found the Indians smoking and drying meats and fish. Salt had long been employed for preserving food; formerly meat to be used on long ocean voyages was packed in barrels of strong salt water.

And early in the seventeenth century Francis Bacon, experimenting with freshly killed fowl placed in a snowdrift, proved that cold preserves food. But no one knew why these practices helped. *Exercises 1, 2.*

Now it is known that although drying does not as a rule kill bacteria it certainly keeps them from growing and reproducing; they feed by absorption and in dried food there is not enough moisture to permit of osmosis. It is also known that vinegar, spices, and sugar, if sufficiently concentrated, preserve food because bacteria cannot thrive in the presence of these substances. They act as mild antiseptics and they serve their purpose well, especially since they are relatively harmless to the cells of man's digestive tract. In canning, manufacturers sometimes use chemicals or food preservatives such as benzoate of soda. These substances if taken in considerable amounts are more or less injurious to the body. This practice of adding preservatives became so common some years ago that it was necessary for the government to pass the Pure Food and Drug Act. This act forbids the use of certain chemicals, restricts (keeps down) the use of others, and demands the labeling of the contents of every container.

Man has learned too that low temperatures such as those in refrigerators keep bacteria from reproducing. Therefore, if the bacteria are not too numerous to start with and the temperature is kept steadily low, food will remain fresh for long periods of time. But once let the temperature rise and food spoils very rapidly.

On the other hand, heating to 150 degrees Fahrenheit or more not only is unfavorable to growth but kills many bacteria. However, this is only a temporary measure, for other bacteria settle on the heated food and decay it. *Exercises 3, 4, 5.*

Why does canning preserve food indefinitely? In canning, food is packed in containers and heated under pressure. The cans are immediately sealed so that bacteria will be unable to enter. If the heat is sufficient to kill all bacteria and no others can get in before the can is sealed the food within the container cannot decay, no matter how long or under what conditions it is kept thereafter.

Some people have the mistaken idea that the reason why canned foods stay fresh is that oxygen is excluded and the bacteria die for lack of oxygen. This is not the reason, as the following facts show. It is true that all bacteria must carry on oxidation in order to grow and reproduce. But there are certain species of bacteria that grow better when oxygen of the air is scarce or even entirely lacking. They obtain all the oxygen they need by breaking down foods, for in this breaking down tiny quantities of the gas are given off. Such bacteria are said to be *anaerobic* (an-a-er-o′bic — not air-living). The anaerobic bacteria, therefore, would find the food in an airtight can entirely suitable to their needs. It is true that the majority of bacteria are *aerobic* (a-er-o′bic — needing free oxygen) but since anaerobic species exist it is not possible to use the exclusion of air as a method of preserving foods. There must be complete sterilization before foods are sealed in airtight containers.

Courtesy W.P.A. & N.Y.C. Bd. of Health

FIG. 341. In the baby clinic. Constant care ensures good health.

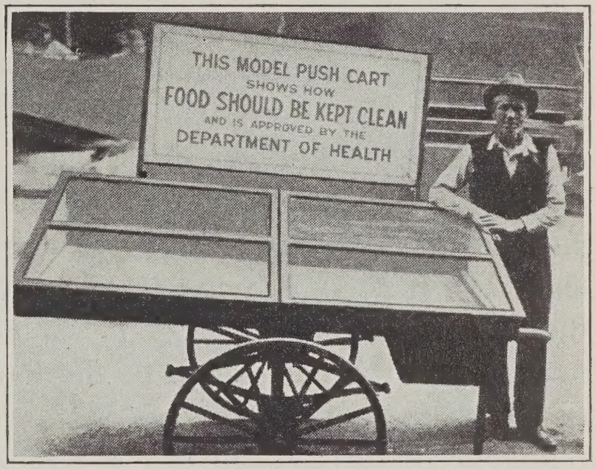
Why are pathogenic germs more difficult to guard against than those that decay food? The problem of keeping food from spoiling is comparatively easy. You can permit bacteria to settle on the food and then take steps to hinder their further growth and reproduction. But in dealing with microorganisms that cause disease you cannot permit them to go so far. You must fight them at long range, for once they are inside your body you may have a real problem on your hands. Of course, wise people nowadays keep all kinds of antibodies in their blood stream for the same reason that some people keep the shelves of their medicine chests stored with useful medicines: in case an emergency should arise. But there are so many diseases against which science has not yet found a method of inoculation that even the best blood serum has many empty "shelves." For this reason you must learn in what quarter you may expect the attack of microorganisms and keep them from entering.

What can man do to keep microorganisms from entering his body? Scientists have helped man to keep microorganisms from entering his body by showing him how the various common disease germs may enter. Studies show that some germs come in through the mouth with the food or drinking water. More enter through the nose in breathing; while others come in through the broken skin, either with a wound or the sting of an insect. Man, therefore, tries to keep pathogenic bacteria from food, especially milk; he purifies the drinking water; he attempts to kill off the insects which are known to carry disease. But how keep out the rest? In spite of all precautions bacteria find their way in.

The problem of how they could keep bacteria from entering seemed too difficult for solution until it occurred to scientists that they could more successfully keep bacteria out if they knew how each kind of bacterium escaped from the body of the patient. Instead of merely attempting to guard the entrances of the many healthy human beings it seemed more helpful to guard the exits of the few suffering from disease.

Biologists succeeded in doing this by *quarantine* (quar′an-teen), the separation of the patient from other people. Quarantine does not mean that the patient need be far removed; all that is necessary is that he must not be permitted to use or touch objects handled by others. Quarantine (or *isolation*) demands that neither the sick person nor his possessions can come so close to the well person that a direct transfer of germs is possible. Thus bacteria are stopped at their source, the diseased body, and prevented from entering your body or mine. Many epidemics have been avoided in this way. Formerly a health officer would disinfect or *fumigate* (disinfect with fumes) room, clothing, and all utensils after a case of infectious disease. Now scientists know that bacteria die very quickly in the air and they do not, ordinarily, trouble to fumigate the sick room.

What precautions other than quarantine can be taken to keep bacteria from spreading? It was soon realized that, in spite of careful quarantining, pathogenic bacteria always appeared again, to attack the well and to puzzle the scientists. What could be their source? Most pathogenic bacteria, for example, diphtheria germs, cannot live outside an animal's body for more than a few hours; in many cases the patient was quarantined so that he could not spread his bacteria to others, and yet there were always new cases of diphtheria. In other words, guarding the exits did not seem to stop the spread of bacteria as successfully as had been hoped. It was then that scientists discovered a startling fact. In some cases, even after a person has recovered completely from a disease, living bacteria remain within him for a shorter or longer time. Such a person becomes a *carrier* of those particular bacteria. But worse than that! Many people carry pathogenic bacteria without ever having been attacked by the disease normally caused by such bacteria. These people are carriers, too. And the carriers may be other animals as well as human beings. Thus, to keep disease germs from entering our bodies the health officer must be prepared to deal with a variety of carriers.



Courtesy Am. Mus. Nat. Hist.

FIG. 342. What does this picture teach you about the care of food in stores or at home?

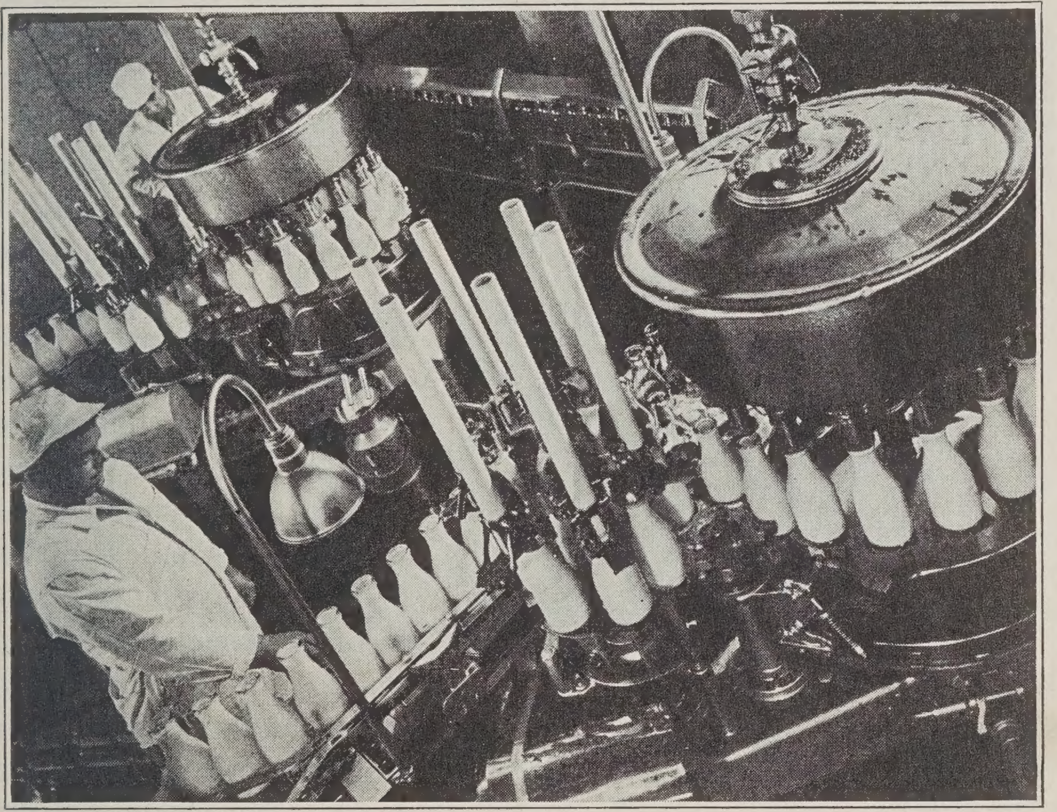
How can the spread of bacteria by human carriers be prevented? If well people are harboring and spreading bacteria it becomes increasingly difficult for you to keep the germs from entering your body. The individual can help to protect himself by observing the rules of cleanliness, such as washing his hands before eating, and by carefully keeping up his vigor by observing the rules for good health. Having established a few good habits of this kind, man may forget about bacteria, but only after he has made sure that the medical officer or board of health is protecting him sufficiently. A medical officer can demand the correct type of drinking fountain; he can forbid the use of public towels; he can license those who handle raw food for sale and demand a medical examination of such people; he can demand certain standards of cleanliness in food stores and restaurants, such as wrappers when possible, glass cases over foods on display, and thorough cleansing of dishes. There is much a board of health does nowadays to protect the community against the bacteria which are always being spread both by the diseased and by carriers.

What other animals may be carriers of disease? You read in an earlier problem how the malaria protozoan is carried from one person to another by the Anopheles mosquito. Some years after this great discovery it was learned that the organism which causes yellow fever is also carried by a mosquito, a mosquito of quite a different species, one which cannot survive winters in the temperate zone. Yellow fever was a dreadful scourge in the tropics until man learned to fight not the immediate cause but the carrier. The history of this great discovery is an interesting one. Two privates in the United States Army, John R. Kissinger and John J. Moran, volunteered to risk their lives in order that a scientist might find out how the disease is really spread. Kissinger allowed himself to be bitten by a yellow fever mosquito which had sucked the blood of a yellow fever patient. Moran slept in a dirty, stuffy hut in which yellow fever patients had just died, using the bedding and dishes left by the previous occupants. Moran had the better end of the bargain, as events proved. He got off scot free, for the yellow fever organism cannot enter the body except through the bite of a mosquito. Kissinger came down with a bad case of yellow fever, suffered horribly for days, but finally recovered. He paid heavily for his sacrifice, for his health was seriously impaired by the experiment. *Exercise 6.*

These were the first of the experiments which later definitely proved that only the yellow fever mosquito can carry the germ from one person to another. Once this had been established, the duty of the scientist became clear: he had to discover a way of wiping out the carrier. This was easier than attacking the invisible germ. In the next problem you will learn by what measures mosquitoes have been successfully fought.

There are other carriers of microorganisms. All through the Middle Ages and well into modern times Europe was visited now and again by dreadful plagues. The Black Death was one of these. In most of the plagues the disease seems to have been one that still claims many lives in the East — bubonic plague. It breaks out occasionally in our seaport towns which are visited by steamers from the Orient. These vessels, like all ships, are the homes of rats, which can catch bubonic plague. The disease is spread from one rat to the next by fleas. When the rat dies the fleas jump to another rat or to man and transfer the bacteria to this new host.

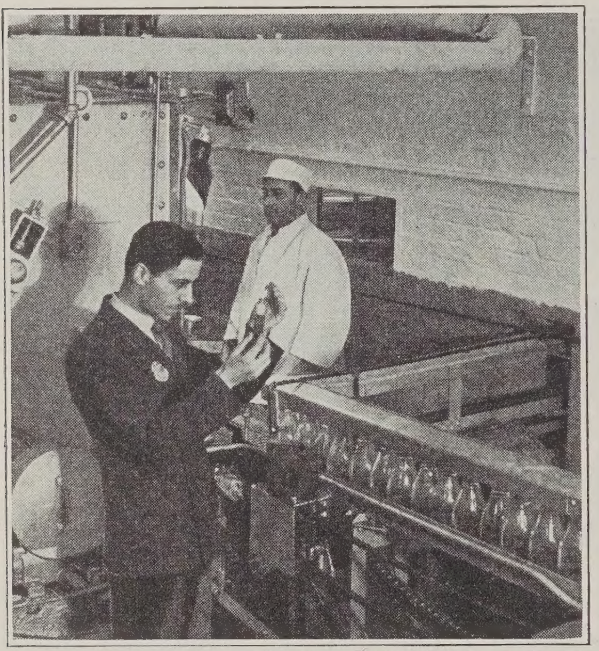
The list of disease carriers is a long one, including many animals besides man, the rat, the flea, and the mosquito; and the list is continually growing as medical research goes on.



Courtesy National Dairy Council

FIG. 343. The milk bottles are filled when they are under the tanks and capped by the machine holding the paper tubes. What is the advantage of having all this done by machine?

How can pathogenic bacteria be kept out of milk? You learned above that food can be protected to some extent against disease bacteria if examination and licensing make it impossible for disease carriers to handle food in the market and the kitchen. Keeping the foods well covered also helps. But with milk the danger of contamination is very much increased. Microorganisms which would die off rapidly in other foods, live and even multiply in milk. Then, too, cows suffer from some of the diseases that affect human beings and the bacteria are likely to get into the milk from the infected cow. This is true of the tuberculosis bacillus, for instance. Milk also, unlike most other animal foods, is often consumed raw. For a long time milk has been recognized as a source of danger in the spread of disease. People began boiling the milk they drank, but this changes the flavor. So they tried the process which Pasteur had used on wines and beers to keep them from spoiling. They called the process *pasteurization* in his honor.

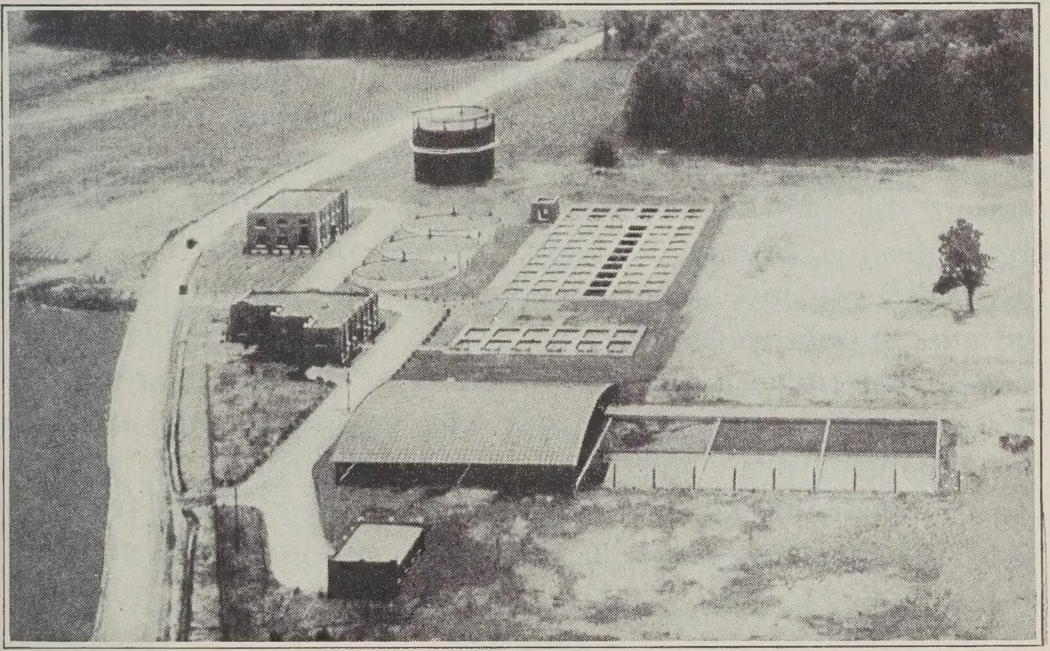


Courtesy N.Y.C. Bd. of Health

FIG. 344. The Board of Health inspector making a test in a milk plant. What may happen if he is careless or is not well trained and skillful?

When milk is pasteurized it is first heated to a temperature of about 150° F. for about half an hour. This is far below the boiling point and the milk is not made less digestible nor is its flavor changed to a great extent. But the temperature is sufficient to kill the pathogenic bacteria that may have entered by accident since spore formers do not live in milk. It also kills some of the other bacteria which swarm in even the cleanest milk. This heating does not kill the milk-souring bacteria but it stops their growth for a few hours. If, therefore, the milk is iced immediately after it has been subjected to heat and is then kept in a cold place, it will not sour. *Exercise 7.*

How does man safeguard his water supply? You do not get pneumonia from drinking water, nor tuberculosis, nor measles, nor most of the many diseases that might come to your mind. In the first place the bacteria that cause these diseases rarely find their way into the water; and in the second place, they do not live long in water. There are relatively few kinds of pathogenic bacteria that enter the body by way of drinking water, but those few are likely to do great damage once they get in. They are the bacteria that settle in the intestines and pass out with the excretions. Unless sewage is carefully disposed of, the bacteria may be washed by rains into the nearest stream or into a neighboring well. Such water is said to be *polluted* (pol-lut′ed). Mixed with particles of decaying matter these bacteria can live for weeks or even months in the water. They even survive when the water freezes; when they are thawed out they are just as active as ever. Typhoid fever and, in warmer countries, cholera, are two diseases which may be spread by polluted drinking water.



Courtesy P.W.A.

FIG. 345. Many cities nowadays dispose of their sewage in plants like this (Durham, North Carolina), instead of letting it flow into streams or into the ocean to be diluted and carried away.

There are two things a community must do to protect itself against the water-borne diseases. Its first responsibility is to dispose of its sewage. Dumping sewage into rivers or the ocean is unwise because bathers may contract intestinal diseases. The second responsibility of the community is to safeguard its drinking water. Water free from all pollution is not easily obtained for large communities. Some cities, like New York City and Los Angeles, construct huge reservoirs many miles away. The water in the streams and lakes of the watershed is guarded against pollution. Before it enters the huge pipes that carry it to the city, it is aerated (mixed with air) and otherwise cleansed. Other cities follow a different practice. They collect the available water, even if possibly polluted, and then purify it by passing it through huge sand filters and treating it with chemicals like chlorine which kill the microorganisms.

By what methods has man learned to keep harmful microorganisms at a distance? Man had to discover much about the habits of microorganisms before he knew how to keep them at a distance. He discovered that there are many kinds which settle on his foods, souring milk and decaying other foods. He learned how to preserve his foods, sometimes by warding off bacteria, sometimes by killing them after they had settled. But more important still was the problem of keeping the pathogenic microorganisms from entering his body. He has concentrated his efforts on five different methods: controlling the water supply, controlling the milk supply, protecting the healthy against possible human carriers, exterminating insect carriers of germs, and guarding the diseased so that their germs may not be spread. By applying these methods many epidemics may be prevented; as more is learned about the ways in which germs enter and escape from the body, infectious diseases will become less and less common.

Exercises

1. *Demonstration.* To show the effect of salt, vinegar, spices, and sugar on the growth of bacteria. Place small pieces of meat in a series of test tubes and add smaller and larger amounts of each of the above preservatives. You can roughly judge the effect of the preservative from the odor and appearance of the meat after some days.

2. What is the effect of dryness on the growth of bacteria? Nutrient agar consists mostly of water. Therefore, open a petri dish so as to permit the water to evaporate. Do this where bacteria are not likely to enter. Then expose it and another petri dish to the air of a crowded corridor for a few minutes. Close the latter dish and put both in a warm place. Observe after 48 hours. What do you conclude about the effect of dryness on the growth of bacteria? Are you now entitled to draw conclusions or to generalize on the effect of dryness on bacteria? Is this a valid experiment? Discuss.

3. What is the effect of cold on bacteria? Provide yourself with four sterile petri dishes. Add a few drops of milk to two of them; expose two others to the air. Place one of the first two and one of the second two in an ice box. Leave the others at room temperature. Observe after 24, 48, and 72 hours. Keep accurate notes. Why do you keep some at room temperature? Why do you expose plates to both air and to milk? Can you now give a final answer to the exercise question? Why or why not? What could you do to find out whether the bacteria had been killed?

4. How could you show that boiling kills all or most bacteria?

5. Carefully study the labels on a variety of cans, jars, and bottles of food. Do you find any which contain preservatives? Explain.

6. What experiments must have been carried out to show that yellow fever is transmitted by a mosquito? Write in outline the plans for such experiments. Are you sure that you would be justified in drawing conclusions from these experiments?

7. How does the number of bacteria in various grades of milk differ? Where milk of grades A, B, and C is sold, it would be interesting for you to find out what different standards are set for each grade and to compare the number of bacteria in the various kinds. You will need nutrient agar in petri dishes, sterile distilled water for diluting the milk, some sterile pipettes, glass bottles, etc.

Problems for Classroom Discussion

1. Remembering what you have learned about osmosis, explain why sugar and salt may be injurious to bacteria.

2. Why might canned food that is decaying cause the can to swell?

3. Why may wrapping newspaper about the ice in the ice box be poor economy?

4. Why are there more likely to be cases of food spoiling as a result of home canning than as a result of commercial canning?

5. Why is the use of food preservatives unnecessary in the canning of foods?

6. Explain how Koch's techniques enable the physician to detect a carrier of a disease.

7. List all the rules of cleanliness that food handlers ought to observe. Give reasons for these rules.

8. Why does drinking water carry the germs of intestinal diseases but rarely carry diphtheria germs?

9. Towns sometimes pipe sewage to the ocean near oyster beds. Explain why this is dangerous to the health of persons both in the town and in other places.

10. *Summary.* If the class is broken up into committees, the work of summarizing this problem can be done most effectively. Each committee can consider a different bacterium. How many committees will be needed? In each case list all possible ways in which the bacterium may be kept at a distance. About which bacteria have laws been passed? Can you suggest what you might do to help enforce such laws? Could you suggest other possible regulations to help prevent the diseases you are considering?

Activities for the Junior Biologist

1. You can grow a pure culture of anaerobic bacteria in a test tube of agar. Obtain such a culture from a biological supply house. Pick up some of the colony with a sterile needle and plunge the needle into a test tube partly filled with sterile agar. The needle should go well down into the agar. Plug the test tube and set it aside for a few days. How does this colony differ from those that grow on the surface of the agar?

2. Visit a large food market. Report on the precautions that are taken in the handling of food. Can you suggest any practicable improvements?

3. Read Defoe's book *In the Year of the Plague.* Report to the class.

4. Visit a large milk distributing plant in your city. Note particularly the steps taken to prevent contamination of the milk. If you live in the country, visit a farm that supplies milk to your neighborhood. What precautions do they take to keep the milk pure?

5. Are you sure that the water supply in your home is pure? What are the possible sources of contamination?

6. How is sewage disposal effected in your community? Is it likely to contaminate the water supply? The bathing beaches?

7. Capture a housefly and let it walk across a sterile agar plate. Put the plate away in a warm place for a few days. What do you discover?

Problem 3. What Measures Are Used by Man to Defend Himself against the Larger Competing Organisms?

Which animals are man's serious enemies? The tiger and the boa constrictor, the rhinoceros and the crocodile, the shark and the octopus occasionally attack man but they are not important foes. A second type of attack on man comes from such animals as the foxes and those hawks that rob the poultry yard, from the robins and bluejays that spoil ripe fruits, from the crows and grackles that steal corn, and from the starfish that devour large numbers of oysters. These animals compete with man for food.

But these are not important rivals, either. They take so little that many biologists are convinced that the harm they do is more than balanced by their value in the general scheme of forest and field life. There is, in fact, only one foe, aside from bacteria, that seriously threatens man by its attacks — the insect. To the city-dweller the tiny insect may seem a weak opponent. But the boy or girl who has watched it at work on the farm knows that it eats large quantities of man's food. Of course, not all the species of insects are enemies of man. Some are even helpful to him in one way or another. But there are scientists who believe that in the long run insects will prevent the increase of man's numbers because so much time and money will have to be spent in fighting them. Indeed, one of the greatest students of insect life, Dr. Leland O. Howard, has written a book entitled *The Insect Menace* in which he states his conviction that only the most careful planning can save man from final defeat.

Why are insects such dangerous rivals? In an earlier problem you read that biologists have found and classified more than half a million different species of insects. Each species differs from its closest relatives in one or more small ways that probably give it an advantage in some particular environment. Insects are adapted to live under almost all conditions. Some remain comfortable in freezing temperatures, others in the bubbling waters of hot springs. They are adapted to feed on and digest articles which to other animals would have no use as nourishment: wood, paper, clothing, even face powder! Some are so small that they can hide in any crack and find food enough for their wants. And not only are there many species but each species includes countless individuals, for insects reproduce in large numbers.

In what ways are insects a menace to man? Among the insects that attack man directly are the germ-carrying mosquitoes, the flea which transmits bubonic plague, and the body louse responsible for a disease known as typhus. There is also a fly, the tsetse fly, which carries the protozoan that causes African sleeping sickness. The tsetse fly is not found in America. But there are large sections of Africa into which men may not enter freely because the dreaded tsetse fly lives there. The recent discovery of a drug which can be used to combat the disease may enable man to push into this territory, but the victory has not yet been won.

The insects that launch an indirect attack are much more common. Insects attack man's crops, plants standing in the fields and grains gathered and stored. It has been estimated that one tenth of all crops are destroyed by insects. For one tenth of his working day, often for one long hour each day, the farmer toils for the benefit of another creature. Most of this loss is caused by insects that eat the plant. But insects are destructive to plants in another way, also; some of them are responsible for carrying plant diseases known as blights and wilts from one plant to another. These diseases spoil the crops.

Some insects kill trees in cities and in forests by eating them clean of foliage; others, by eating the wood and bark. Death may come to the tree slowly or rapidly, depending on how the insect does its work. But the loss to the United States is probably not less than $150,000,000 every year.

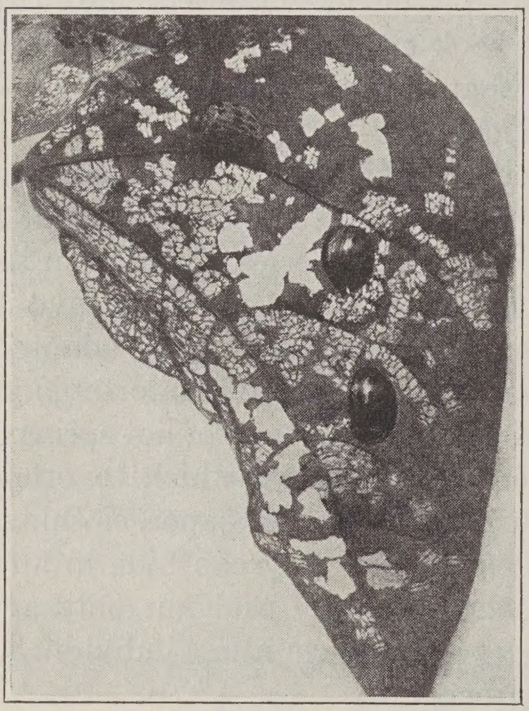


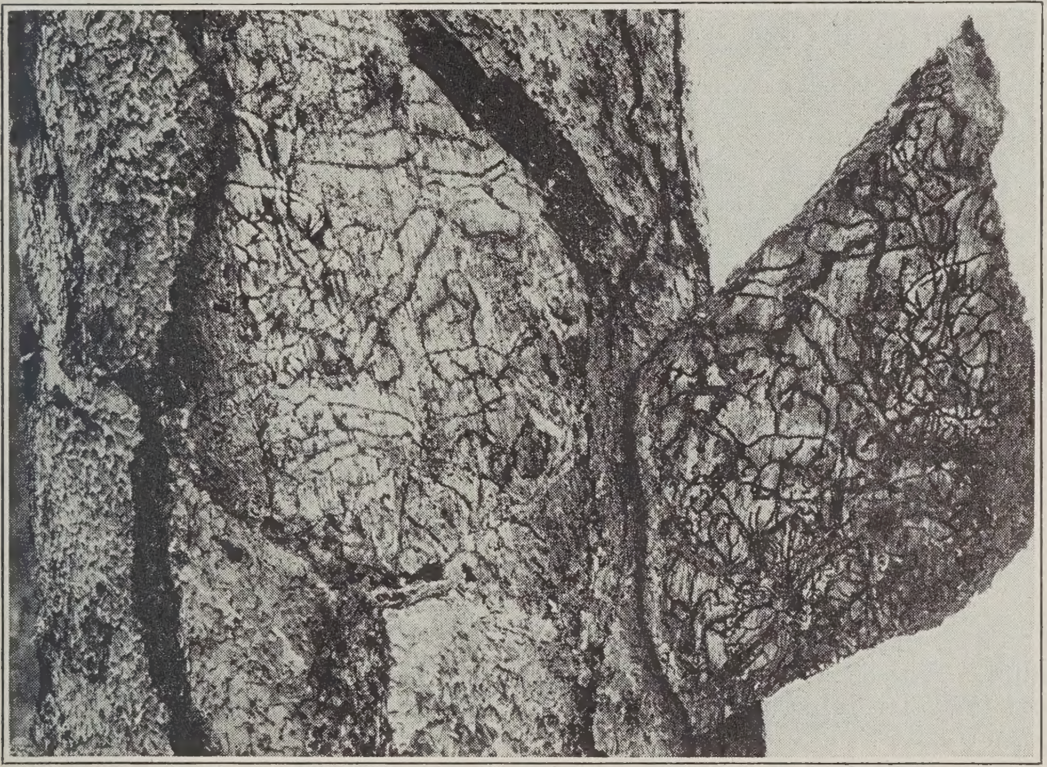
Photo by H. Schneider and J. Schwartz

FIG. 346. What effect does the Mexican bean beetle have on the string bean plant?

Insects attack domestic animals. Lice, fleas, horseflies, and many other species sap the strength of the animals on the farm or spread disease among them. Still others may destroy the wooden framework of your house, the carpets on your floors, the paper on your walls, and the clothes in your closets. While the loss caused in these ways is small in comparison with the losses sustained in forest and field, it is far from unimportant. At every turn one or another species of insect competes with man for room on this earth; and the fact that the competition is often indirect does not make it less important.

What is man's only hope of conquering insects? Man's one great advantage over insects is his brain. This enables him to plan successfully against organisms so well adapted to various environments as are the insects. But to be successful in their warfare against insect enemies, men must work together. For this reason the Federal Government established a Bureau of *Entomology* (en-tom-ol′o-jee — study of insects). Until recently Dr. Howard was chief of this bureau and directed the work of large numbers of entomologists. He himself became interested in this work as a very young boy and began making original observations while still at school.

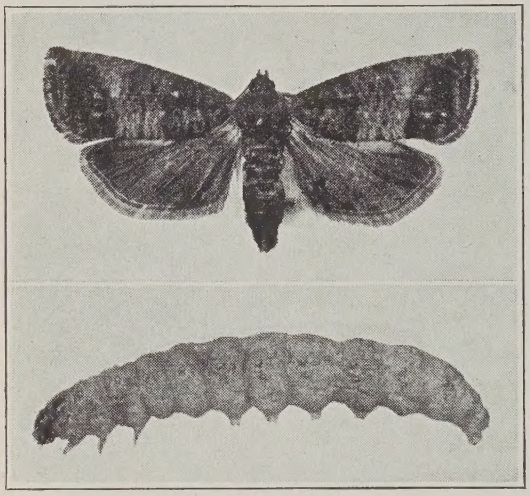
Assisting in the work are the Agricultural Experiment Stations of the various states. Insect control is one of their important functions. Entomologists must know exactly how each insect feeds and where and how it breeds. A method of attack that will work in the case of one insect usually proves useless against another because insects themselves vary so much in structure and in habits. You will read of a variety of methods used by entomologists. *Exercise 1.*



Courtesy U. S. Forest Service

FIG. 347. A piece of bark raised to show the tunnels of the pine beetle. The eggs are laid in them. Why does this injure the tree?

How does man use chemicals to destroy insects? You have all seen the cabbage butterfly, for it is very common; a small white butterfly with a wing spread of about two inches. It sucks nectar from the flowers to which it flits. In time it lays eggs on the cabbage plant and in two weeks these grow into caterpillars with strong jaws for biting leaves. The smooth, inch-long, green caterpillars match the dull bluish green of the cabbage so exactly that they can scarcely be seen when at rest. Like other caterpillars they are always hungry and that may lead to their undoing, for the leaves of the cabbage plant may be thoroughly sprayed with a compound poisonous to the insect. It swallows the poison with its food. Although this method of combating the cabbage butterfly by means of "stomach poisons" has long been known, the insect traveled from Canada to the Gulf of Mexico within eight years, damaging cabbage patches along its route. In part, man's failure to prevent the spread of this undesirable insect was caused by the fact that even in climates where the summer is short, the cabbage butterfly produces three broods in a season. In part, man himself is responsible; few farmers took pains to spray their plants.



Courtesy U. S. Dept. Agric.

Fig. 348. The codling moth, larva and adult. Which has biting mouth parts and will be injured by a stomach poison?

The codling moth, which attacks apples and pears, is even more destructive than the cabbage butterfly. New York State alone pays an annual toll of $3,000,000 to these insects. It is probable that you do not know the small adult moth for it matches the color of the bark on which it rests. But you must have met the caterpillar in a "wormy" apple. If the apple that has been attacked falls to the ground before it is ripe, the larva eats its way to the surface and crawls out to spin a cocoon. Well concealed, these cocoons last through the winter. In early spring the young moths emerge and promptly lay eggs on the leaves of the apple tree. When the eggs hatch into larvae, the tiny caterpillar has but a short journey to the fruit, which is just starting its development. The caterpillar bores into the developing apple, eats well, and grows as the fruit gets larger.

By spraying stomach poisons of lead arsenate at just the right time this pest can be partially controlled. The spraying, unfortunately, is not altogether successful because the codling moth may have as many as four generations in a year and sprayings late in the season are not as successful as those done when the fruit is young. Because lead arsenate is very poisonous care must be taken that the fruit is thoroughly washed before being eaten.

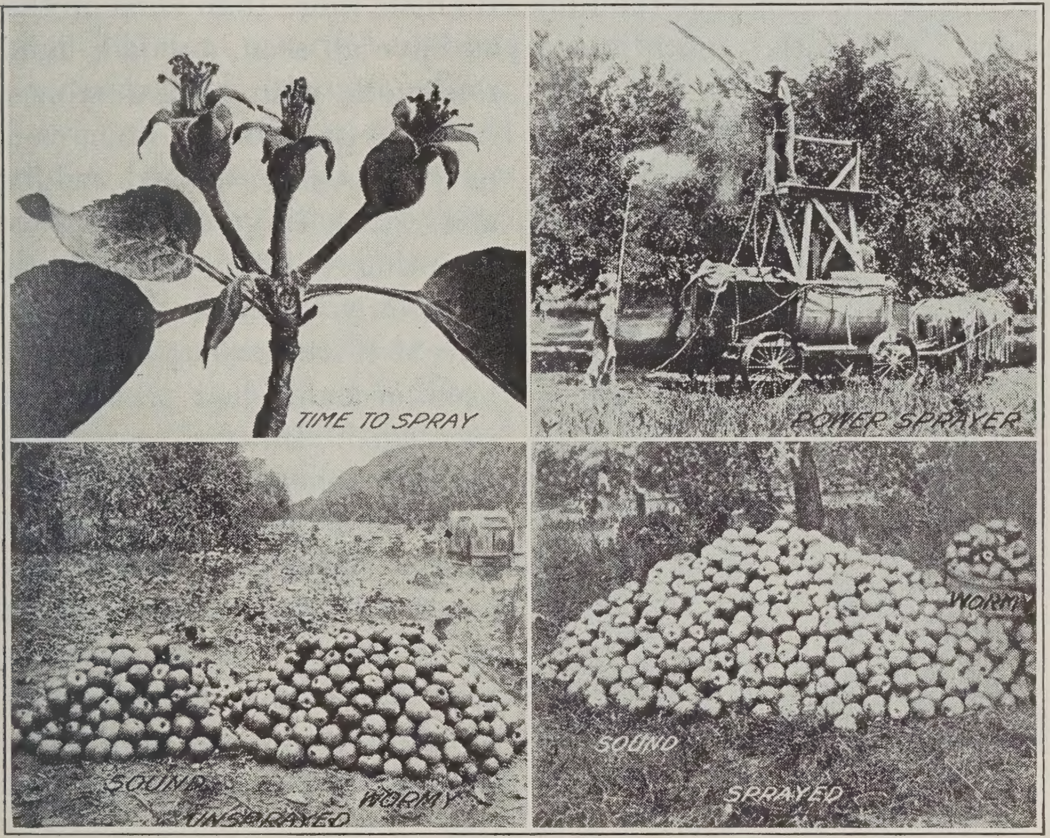
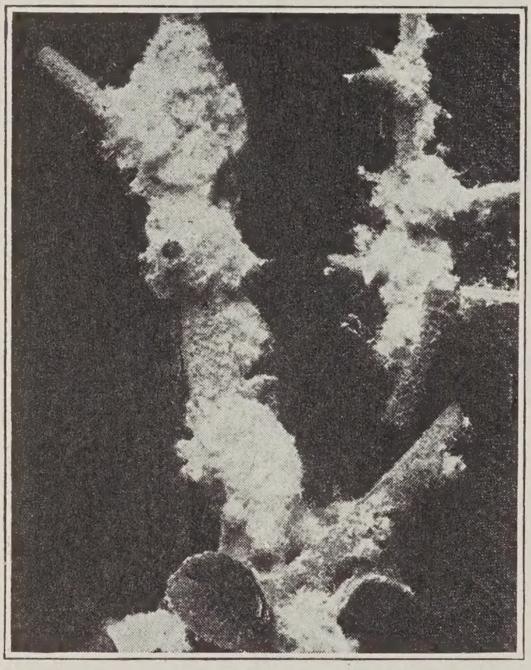


Photo J. A. Hyslop, U. S. Bureau of Entomology

FIG. 349. What do the heaps of sound and wormy apples indicate about codling moth control?

But not all insects can be killed with stomach poisons. When an insect does not have biting mouth parts in any stage other weapons must be used against it. The plant lice and the many scale insects are of this kind. They puncture the stem or leaf and suck the juices of the plant. In this case the chemical used must be one that destroys by coming in contact with the outside of the animal. "Contact" solutions of nicotine or even of soap are often used for spraying house plants infected with sucking plant lice; contact sprays are also used to rid fruit trees of scale insects. Kerosene or other oils may be used in the spray.

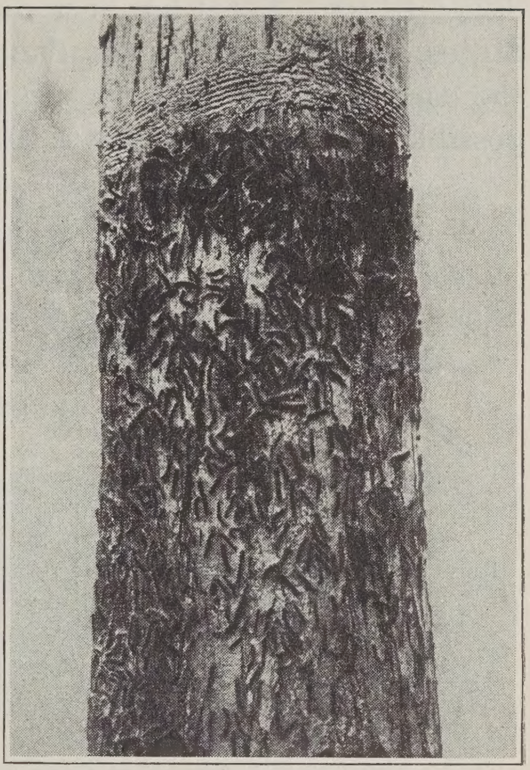
Sometimes, instead of using liquid sprays, chemical fumes are applied to the tree, which is first covered with a sort of tent. Powerful poisons can be used in this fumigation against scale insects without injuring the fruit or the tree. The same theory of protection by fumes leads you to fight the clothes moth by putting camphor or naphthalene in clothes chests and closets. It is probable, however, that the fumes do little more than keep moths away. The clothes moth is one you have all seen, a small, light tan moth with ragged wings. At one time or another you have probably dashed wildly after this tiny creature, attempting to slap it to death between your hands. You may have felt that something had been accomplished when you succeeded. But you were wasting your energy, for the little moth had laid its eggs and started the next generation before it left its dark hiding place to fly about. While you pursued the adult, the egg was developing into the tiny larva so destructive of wool and fur.



Courtesy U. S. Dept. Agric.

FIG. 350. The woolly aphid on apple twigs. How did this scale insect get its name?

How does man trick insects to their deaths? The chinch bug is a tiny insect less than a quarter of an inch long, yet it reproduces with such rapidity that in some years it causes losses in the grain fields of the Mississippi and Missouri valleys that are counted in millions of dollars. The eggs are laid in the ground or on the young stems of grains or wild grasses. Like all bugs the chinch bug has sucking mouth parts which the young begin to use as soon as they are hatched. After five or six weeks the bugs are full grown and by this time their feeding ground is pretty well exhausted or the plants have grown too tough for the tiny mouth parts. Then they migrate in vast hordes. Though they have wings they march on foot to a neighboring cornfield. They move forward blindly so that millions can often be trapped by kerosene-filled ditches. This is only one of several ways in which the farmer fights the chinch bug.



Courtesy U. S. Dept. Agric.

FIG. 351. This tree was banded so that the gypsy moth caterpillar could not crawl up the trunk to the lower leaves.

The gypsy moth has found its way into the eastern states from Maine to New Jersey, stripping and, in time, killing trees. It eats almost any kind of leaf, even the needles of the evergreens. The female lays the eggs during the summer in large clusters on the bark of trees, on fallen logs, fence rails, or even on stones in sheltered places. These eggs winter over and hatch in early spring. Shortly after they come out, the dark, hairy little caterpillars start to move up the trunk in search of fresh green leaves. It is then that they can be trapped by banding the tree.

Besides using such simple barriers, entomologists are experimenting with devices for luring insects into traps by means of lights or strong odors. The oil which gives the characteristic odor to the geranium plant is so attractive to the Japanese beetle that it follows the scent even at the cost of its life. Perhaps at some future time this can be made use of on a large scale to exterminate this recent but already very serious pest.

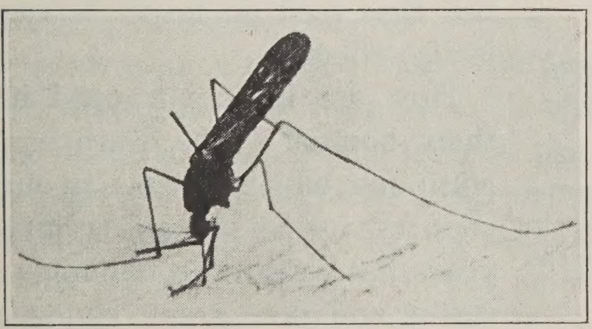


Photo by Science Service

FIG. 352. The malaria-carrying mosquito (Anopheles) sucking blood. Compare the angle of its body with that of the Culex in the diagram. How can you tell them apart?

How has man used his knowledge of breeding habits to destroy insects? Exterminating mosquitoes in populated regions is a difficult task. Yet it has been done in some sections of the United States, in Cuba, and in the Panama Canal Zone. In fact, it was the control of the mosquito pest in the Canal Zone that made it possible for the United States to accomplish what the French had unsuccessfully attempted. You will remember that mosquitoes lay their eggs on still or slowly moving water, and the tiny larvae wriggle about in this water, coming to the surface to breathe. With the filling in or draining of each stagnant pool, thousands of mosquitoes are kept from developing. By doing this thoroughly the mosquito can be robbed of its breeding places. When this is not possible the thinnest film of kerosene spread over the water will suffocate the larvae and pupae. When they rise to the surface they are unable to come in contact with the air and soon die. In some cases stocking the waters with small fish that feed on insect larvae is also effective.

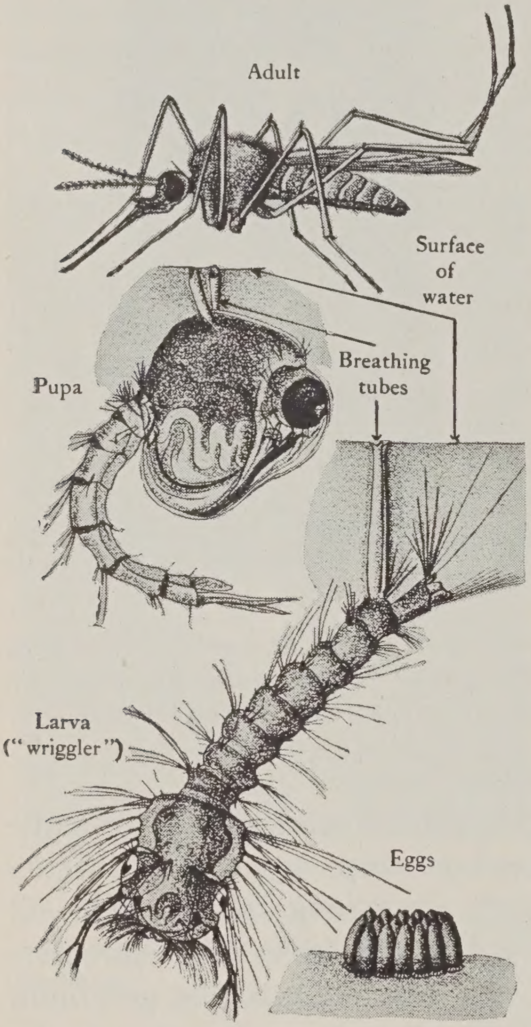
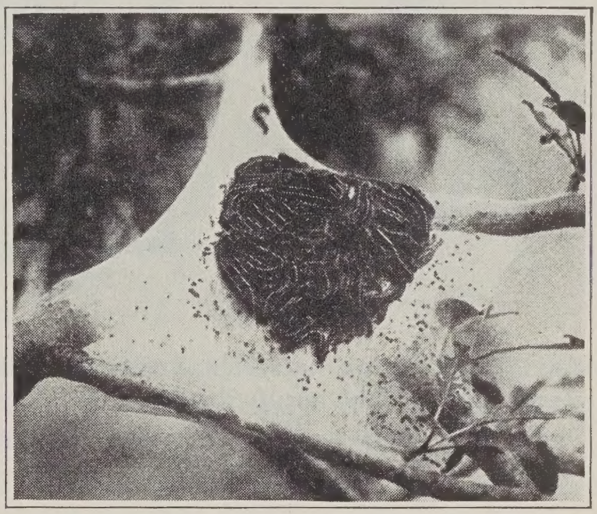


FIG. 353. The life history of the common mosquito (Culex). How does the information given by this diagram help the public health official to control the insect?

How are insects trapped in their homes? The European cornborer, which has been in our country for less than twenty years, has spread through many states and does great damage. The small moths are good fliers so that their spread is rapid. The moth lays its eggs on the leaves of the corn; lacking corn, it contents itself with many other plants, among them some of our commonest weeds. When the larvae hatch they feed on the corn for a few days and then enter the stalk, within which they spend the winter. This is unusual; in the case of most insects it is a pupa which winters over. In the spring the larvae spin cocoons, and soon after that come out as adults. If the remains of all cornstalks are destroyed during the winter months vast numbers of cornborers are done away with.

The tent caterpillar, too, is easily caught while in its home. In the spring there are often large unsightly cottony masses in the crotches of trees, particularly wild fruit trees. These are tentlike nests inhabited by a large colony of caterpillars which all hatched at the same time. The eggs of this insect are laid in batches of several hundred and the young caterpillars remain together. As they grow and need more room they keep adding to their home. During the day the tent is deserted, for the caterpillars are off feeding greedily on the leaves of the tree. Toward evening they return. If the nest is scooped up at this time and burned it is possible to free the tree of the pest. *Exercises 2, 3.*

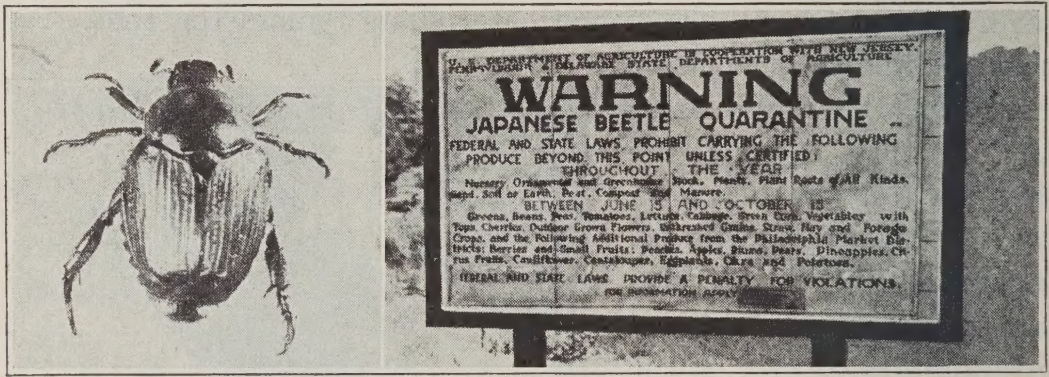


Courtesy Gen. Biol. Supply House

FIG. 354. Tent caterpillars in their nest. When do they return to this tent?

How does man use insect enemies as his allies? The insects that destroy crops, spoil fruits, and kill trees have enemies other than man to contend with. There are birds and larger insects which prey on them. There are other insects and also bacteria which live on them as parasites. The Bureau of Entomology in Washington has long encouraged the protection of such birds as the bluebird, catbird, and kingbird. But more recently it has begun searching for other, smaller allies to help destroy undesirable insects. Many of our worst insect pests are known to have come from other lands. In their native homes they have various enemies, mostly other insects, which keep them in check. Government entomologists have tried to find these so that they might be introduced into our country. Scientists have met with some success in this; for instance they have found in Europe, the home of the gypsy moth, a certain fly which lays its eggs in the caterpillar of the gypsy moth, sapping its strength and killing it. They have also discovered a beetle that eats the caterpillar. The introduction of bacterial parasites has been attempted only within the last few years. Much less progress has been made along these lines. *Exercise 4.*

Against what visible plant foes must man protect himself? Although they are far less important than insects, plant foes must be reckoned with, also. Man's foes among plants are found chiefly among the weeds, plants that are so well fitted to a variety of conditions that they increase in numbers at the expense of other plants. Anyone who has a garden knows the plantains, purslane, quack grass, pigweed, and the many other weeds that seem to grow up almost overnight and turn up year after year no matter what is done to keep them out. *Exercise 5.*


WARNING
JAPANESE BEETLE QUARANTINE
FEDERAL AND STATE LAWS PROHIBIT CARRYING THE FOLLOWING PRODUCE BEYOND THIS POINT UNLESS CERTIFIED:
THROUGHOUT THE YEAR
BETWEEN JUNE 15 AND OCTOBER 15
FEDERAL AND STATE LAWS PROVIDE A PENALTY FOR VIOLATIONS.

Courtesy U. S. Department of Agriculture

FIG. 355. The destructive Japanese beetle has been with us a little more than twenty years. The adults destroy a great variety of plants; the larvae injure the roots of plants. What has the government done to stop the spread of the insect? How might you help?

You can protect yourself against weeds by cultivating the soil and uprooting the plants before they are able to form fruits and seeds. Indirectly you can do much to keep down the spread of weeds by protecting those birds that live largely on the seeds of weeds, such as the tree sparrows, song sparrows, juncos, pheasants, and quail. But weeds are not serious foes as are the insects.

Exercises

1. How does a study of the mouth parts of the insect help to determine the methods of combatting it? If you have not already done so, study the mouth parts of the grasshopper and the moth (or butterfly). What does a study of the mouth parts of a moth tell you about the insect?

2. In which stages of their lives are grasshoppers, moths (or butterflies), and beetles most harmful? If you are not well acquainted with the life histories of grasshoppers and butterflies refer to Part 1, Chapter VI.

3. What are the three or four most harmful insects in your neighborhood? Study the larva, pupa, and adult until you can recognize them. If possible, use specimens. Where may they be found? During what months of the year should they be looked for and fought?

4. What methods of fighting insects are in common use in your neighborhood? If it is not possible to get this information from adults of your acquaintance, ask the class secretary to write to the State Agricultural Station or the State Entomologist. Can you assist in the fight against insects? How?

5. What characteristics enable a plant to become a common weed? Study five common weeds to find out, if possible, why they have become so common. What is there about the roots, the stems, the leaves, the fruits, or the seeds that fitted these plants for survival?

Problems for Classroom Discussion

1. If the damage done by harmful insects costs a total of 50 cents per day for the food and $50 per year for the clothing of the average person, how much do harmful insects cost a family of five persons each year?

2. What are the insects that attack the food materials in your region? (They may attack the growing crops or the foods in stores and household pantries.)

3. Why is it possible for a high school boy or girl to make observations of value to entomologists, as Dr. Howard did? How would the work have to be done?

4. Of the following, which are important in enabling an insect to spread over a large area?

(*a*) Swift locomotion
(*b*) Reproduction of large numbers
(*c*) Eating large amounts
(*d*) Eating a plant that is widespread
(*e*) Eating a large variety of food
(*f*) Living as a parasite in fruit shipped elsewhere

5. Have you successfully prevented damage by clothes moths in your home? How? You might report on the methods you used.

6. Explain why clothes should be sunned and well brushed before being packed away for the summer. Why are newspaper wrappings, if unbroken, as good as cedarized bags?

7. What is there about the structure of insects which makes it possible for contact poisons to work?

8. Why is migration a habit which may be dangerous to an insect?

9. Why do mosquito larvae and pupae rise to the surface frequently?

10. What connection might there be between the invention of the aeroplane and automobile and insect pests?

11. You have learned something about the relation of insects to man. Can you show how insects might affect birds, directly and indirectly?

12. Which insects have ever been beneficial to you personally? How?

13. Is it correct to say that insects are the dominant organisms on this planet? Discuss both sides of this question.

14. Would this be a better world to live in if *all* insects were killed off? Discuss this question.

15. Biologists often define a weed as "a plant out of place." Explain what is meant. Can you provide an example?

16. *Summary.* Are you prepared to discuss man's foes and the variety of methods used to keep down his only real rival? Can you state why it is the duty of everyone to know some facts about man's insect enemies and to give some thought to the subject of the insect menace?

17. *Unit Summary.* Look back to the Unit question. The answer requires such a vast amount of information that it may be difficult for you to give even the important points. But you should know how the methods used by man in his struggle against his foes differ from those used by all other organisms. And you should be ready to show by means of examples how man's success depends on his use of the scientific method.

Activities for the Junior Biologist

1. Make a collection of the harmful insects found in your neighborhood. Mount them for class display. These mounts might illustrate the insects' habits.

2. Read books of travel in the Arctic and the tropics. Report to the class what the authors have to say about insects in those regions.

3. Look through your list of titles of Farmers' Bulletins published by the United States Department of Agriculture and write for those that apply to this study. Farmers' Bulletins 1353 and 1535 will interest you. So will Circular No. 36, Second Series, U. S. Department of Agriculture. You might also consult the publications of your State Experiment Stations. The U. S. Experiment Station Record is exceedingly valuable, also.

4. You will find Surgeon General Gorgas's account of his work in Cuba interesting reading.

5. How many insects can you identify (call by name)? See how many more you can become acquainted with before the end of the year. If you write new names and descriptions in a pocket notebook you can add greatly to your information without difficulty.

6. If you have a flower or a vegetable garden identify the worst weed offenders. Do your observations agree with those of your classmates?

7. If your school grounds are planted, your class or the biology club might undertake spring or fall spraying and weeding.

Good Books to Read

Bayne-Jones, S., *Man and Microbes.* Williams and Wilkins.
Cabot, R. C., *A Layman's Book of Medicine.* Houghton Mifflin.
Cockefair, E. A. and A. M., *Health and Achievement.* Ginn.
Cottler and Jaffe, *Heroes of Science.* Little, Brown.
De Kruif, P. H., *Microbe Hunters.* Harcourt, Brace.
Downing, E. R., *Science in the Service of Health.* Longmans.
Du Puy, W. A., *Our Insect Friends and Foes. Our Plant Friends and Foes.* Winston.
Eckstein, G., *Noguchi.* Harpers.
Fabre, J. H., *Farm Friends and Foes.* Dodd Mead.
Flint, W. P. and Metcalf, C. L., *Insects, Man's Chief Competitors.* Williams and Wilkins.
Haggard, H. W., *Devils, Drugs and Doctors.* Harpers.
Henrici, A. T., *The Biology of Bacteria.* Heath.
Herrick, G. W., *Insects Injurious to the Household.* Macmillan.
Holmes, J. T., *Louis Pasteur.* Harcourt, Brace.
Howard, L. O., *The Insect Menace.* Appleton-Century.
Kendall, A. I., *Civilization and the Microbe.* Houghton Mifflin.
Park, W. H. and Williams, A. W., *Who's Who among the Microbes.* Appleton-Century.
Reese, A. M., *Outlines of Economic Zoology.* Blakiston.
Singer, C., *The Story of Living Things.* Harpers.
Sweetman, H. L., *Biological Control of Insects.* Comstock.
Williams-Ellis, A., *Men Who Found Out.* Coward-McCann.

PART 3

GREAT GENERALIZATIONS OF BIOLOGY

UNIT X. THERE IS UNITY IN ALL LIVING THINGS

1. Living Things Are Basically Alike in Structure and Function
2. Living Things Show Various Degrees of Resemblance to One Another

1. Living Things Are Basically Alike in Structure and Function

The functions of living things. If you will think of yourself as an example of animals in general, you can learn a great deal about the functions of animals by considering the activities in which you engage. Of course, some of your activities are peculiar to man. You attend school, maintain friendships, read books, listen to the radio and do many other things which other animals cannot do.

But consider the basic activities, those which must go on if you are to remain alive. You must take in food (*ingestion*); prepare it for use in the body (*digestion*); change some of it to protoplasm (*assimilation* and *growth*); oxidize some of it, so that energy is produced (*respiration*, which includes breathing); your body must make the substances without which digestion and other processes cannot go on (*secretion*); and wastes produced by oxidation and other bodily processes must be given off (*excretion*). Since your body is complicated the various materials must be carried from one part to another (*circulation*). The one word *metabolism* (meh-tab′o-lism) sums up all these processes. There are other basic activities; you must be able to receive stimuli (*sensation*) and respond as shown in *motion* or *locomotion* or in some other way. And there must be *reproduction* if the race is to survive.

In one way or another, every animal with which you are acquainted performs these *life functions.* And so do plants in a general way. If they are green (contain chlorophyll), plants differ from animals in their method of food getting and so have other functions besides those named above. Green plants make their own carbohydrates (*photosynthesis*) and then build up proteins (protein synthesis). It is not always easy to catch the plant at work; like some of the lower animals (sponges, corals, and so on) the plant performs many life functions without much outward activity. Yet these activities do go on, as the experiments of biologists show.

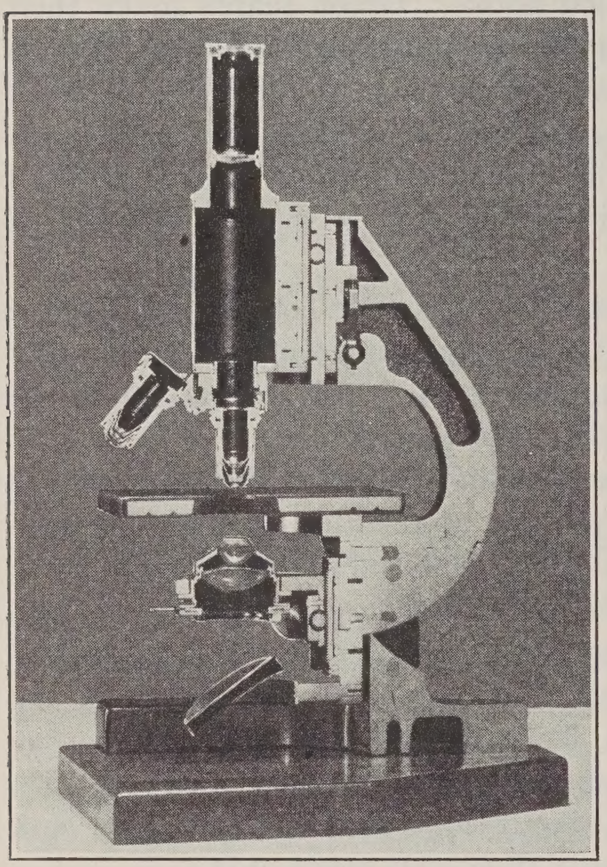
All living things have these life functions in common; if disease or some other factor prevents the organism from performing any one of them (except reproduction), it dies. Living, in fact, is the performance of these activities. *Exercises 1, 2.*

Protoplasm, the physical basis of life. Many of the life functions of organisms had been observed and studied long before biologists knew that there was a special living material that performed these activities. One of the earliest observers to call attention to this living substance was a Frenchman, Felix Dujardin. This was almost exactly one hundred years ago. In the course of his observation of the Protozoa, Dujardin became interested in the behavior of the material which composed these tiny creatures. He decided that it was this active substance that was alive and that the Protozoa were alive because they were made of it.

Not long thereafter a German botanist, Hugo von Mohl, studied the active substance he saw within the cells of plants. He applied the name *protoplasma* (first substance) to it, because he believed it to be the basic living material. Many other biologists devoted themselves to the study of this substance and they soon came to the conclusion that the living material was very much the same in both plants and animals. Thereafter, biologists were convinced that all living things were composed of a special substance which was itself alive and the name, *protoplasm,* found a place in every book on biology. Several years later T. H. Huxley, an English biologist, delivered an address entitled "The Physical Basis of Life." This address made a deep impression on the world and the phrase "the physical basis of life," which he used instead of the term protoplasm, has become famous because it sums up so well the idea that where there is life there must be the substance protoplasm. *Exercise 3.*

The properties of protoplasm. The ameba and the slime mold are two organisms in which comparatively large masses of protoplasm may be found. Close observation of their activities affords a good opportunity to learn something about protoplasm. You have seen that the animal responds to stimuli; protoplasm shows irritability and contractility. You know, too, that the ameba is capable of building more protoplasm; protoplasm has the power of assimilation. The animal manufactures enzymes and other useful substances; living matter has the power of secretion. And not only does the ameba assimilate but it can also divide into two pieces, each of which is self-supporting and independent; protoplasm has the power of reproduction.

All protoplasm can do these things and protoplasm is the only substance capable of doing them. Irritability, contractility, the power of secretion, assimilation, and reproduction are properties characteristic of living matter. The organism is able to perform the life functions because it is made of a substance which has the properties just named. *Exercises 4, 5, 6.*



Courtesy Bausch & Lomb Optical Co.

FIG. 356. The lenses below the stage are not usually attached to high school microscopes. When you look through the microscope you use two sets of lenses. Each set contains two or more separate lenses. Can you find the sets? How many lenses has each set? This section through a microscope shows you how all the parts work. Refer to exercises 4, 5, and 6.

Early ideas about the structure of protoplasm. When biologists first turned their comparatively poor microscopes on protoplasm all they could see was that it seemed to be a thickish liquid, grayish in color, containing small particles and other structures. But when microscopes were improved and methods of dyeing or staining were invented the structure of protoplasm could be studied more closely. Unfortunately, the staining killed the living matter so that biologists could not be sure that the structures which appeared after staining were also present in the living protoplasm. As a result of this confusion several theories of protoplasmic structure were presented by different biologists during the latter half of the nineteenth century. Each one believed his methods were the best and his observations the most accurate. This dispute is no longer of importance; advances in chemistry have enabled biologists to come to some agreement about the structure of protoplasm. *Exercise 7.*

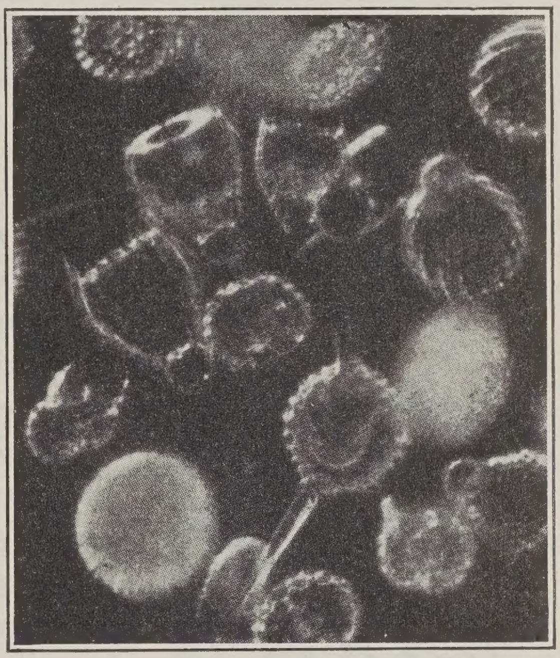


Photo by N. S. Kline

FIG. 357. If the microscope is fitted with an attachment that shuts off the direct light, the light rays pass through the slide at an angle. The object being examined is lighted up against a dark background. These protozoan shells were photographed through a microscope with a dark field attachment.

The structure of protoplasm. You have learned that when substances dissolve in a liquid, as sugar does in water, the particles of the dissolved substance do not sink to the bottom. This liquid is called a solution. On the other hand you have seen large particles, such as form when starch is mixed with cold water, settle to the bottom of the container. But there are some substances which, when mixed with water, form particles intermediate in size; that is, smaller than the starch particles and larger than the sugar particles. These do not sink to the bottom like the starch but they also do not behave like the particles in true solutions. They remain *suspended* (hanging) in the liquid. They are called colloidal (coloy′dal) particles and the mixtures are called *colloids* (col′loyds).

Colloids may be formed in many ways: solids may be suspended in liquids (gelatin desserts); gases may be suspended in liquids (soda water foam); gases in solids (bread); liquids in gases (fog); solids in gases (smoke); and so on. One of the ways in which colloids differ from true solutions is that they may change their structure in unusual ways when heated or when treated with chemicals. When the gelatin dessert is cooled it becomes solid. The "whites" of eggs become solid when heated and turn white.

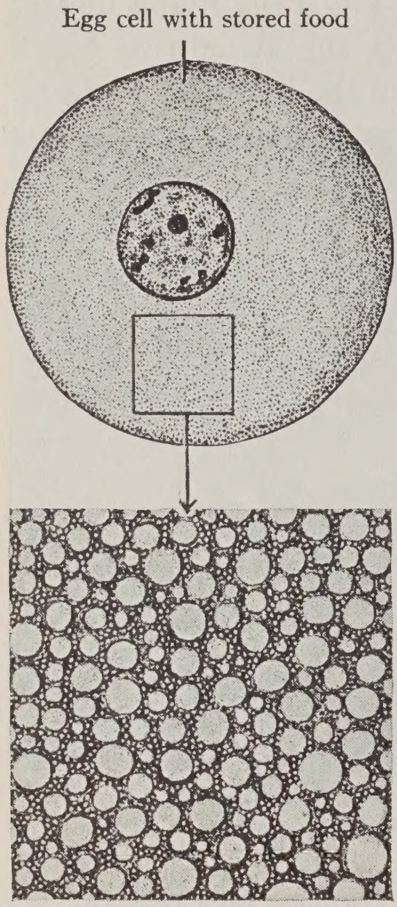


FIG. 358. Above is a diagram showing the egg of a sea animal as it appears under the low power of the microscope. Below is a small bit of the protoplasm highly magnified. How many different sizes of droplets can you find?

The most interesting and important fact about colloids is that there may be many substances in a colloid and the various substances that are mixed may be separated so that they do not affect one another. This can happen because the substances in colloidal mixtures are separated by very thin membranes. In one very tiny bit of colloidal material, therefore, there may be all the combinations mentioned above (solid suspended in liquid, gas suspended in liquid, etc.) as well as true solutions; and each may act in its own way without affecting the others. The behavior of one part of the tiniest bit of material may be altogether different from the behavior of another part directly next to it. This is not true of a solution.

When biologists learned about colloids from the chemist and applied the methods of the colloid chemists to protoplasm they discovered that they were dealing with the most complex colloid of all. Although it is not yet possible to explain the properties of protoplasm, it is generally believed that irritability, growth, secretion, and the other properties are the result of this complex structure of protoplasm. And the knowledge that protoplasm is a colloid and not just an ordinary mixture explained why stained and heated protoplasm did not always give a true picture of the structure. *Exercise 8.*

The substances in protoplasm. Besides being interested in its structure, biologists are interested in finding out what substances make up the complex colloid known as protoplasm. To discover this it is necessary to kill the protoplasm. Therefore, the biologist is not altogether sure that his list of substances is exact.

The substance found in largest amount is water, which makes up more than eighty per cent (by weight) of most protoplasm. Within the water are dissolved many kinds of salts, many kinds of sugars, and some other substances. But within a little mass of protoplasm the water does not exist as a single drop. It is spread out throughout the protoplasm together with many complex substances that do not dissolve in water; such as certain kinds of mineral matter, fats, and proteins. Of these substances the proteins are undoubtedly most important. If you can picture all these substances put together in the complex way described under colloids you will have an elementary understanding of the make-up of the physical basis of life.

Cells and the Cell Theory. One of the most striking facts about protoplasm is that it is found in small masses called cells. As you know, Hooke applied the name cell to the tiny boxes he saw in cork; he was looking at the dead walls of former cells. The men who worked at about the same time or somewhat later, Grew in England, Malpighi in Italy, and Leeuwenhoek in Holland, saw more than Hooke, for they studied living cells. But even they failed to see cells as we understand cells today, for their microscopes were not good enough to enable them to see protoplasm clearly. In fact, it was not until two hundred years after Hooke's discovery that scientists had a true understanding of cells. Finally, in 1861, Max Schultze, a German biologist, came to understand what a cell really is. He stated clearly that cells are really little masses of living matter. This living matter, you will remember, had previously been called protoplasma or protoplasm.

It is interesting to note that even before protoplasm was named, before the true significance of protoplasm was appreciated, and some time before the cell was really understood biologists were already convinced of the importance of the cell to every organism.

Long before Max Schultze showed that the cell is a small mass of protoplasm a French physician and experimenter, Henri Joachim Dutrochet, stated that plants and animals are composed of cells and of substances made by cells. But Dutrochet could not present sufficient evidence to support his theory and for that reason it was not accepted. Fourteen years later, in 1838 and 1839, two biologists, Matthias Schleiden and Theodor Schwann, separately announced the same theory that every organism is made up of cells. Their scientific work had enormous influence because both men presented large numbers of facts and they were recognized as scientists who worked with the greatest care. Schleiden stressed the view that the cell was an independent being or individual; the plant, he thought, was a large mass of cells each of which performed the life processes and thus gave life to the plant as a whole. Because it was alive and because the plant was made up of cells, Schleiden considered the cell of great importance.

Schwann did an even more important piece of work than Schleiden. In a scientific report entitled, "Microscopical Researches on the Similarity in Structure and Growth of Animals and Plants," he presented several important ideas. The first was that the internal structure of plants and animals is similar. Both kinds of living things are made of cells, he wrote, and the structure of these cells is much alike in them.

Schwann further pointed out that the other materials found in plants and animals are produced by cells; the whole organism consists of nothing but cells and materials made by cells. He recognized that cells are alive and that they perform certain activities. He knew, too, that all the cells of an organism work together.

This was the first statement of the Cell Theory, one of the most important general ideas developed by biologists.

Since the time of Schwann the theory has received so much more evidence to support it that no biologist doubts it. It is, therefore, commonly called the Cell Doctrine. Other ideas have been added to the theory since it was first stated. *Exercises 9, 10.*

The structure of the cell. As you know, there are cells of many different shapes, such as spherical, cubical, and so on. The shapes are even more varied than you would probably judge from the pictures you have seen, but all cells, no matter what their shape, have three dimensions, length, breadth, and depth. Differently shaped cells are found within one animal (or plant); toothpick-shaped cells in one part, more or less spherical cells in another part, irregular ones in a third, and flat cells in a fourth. Yet animals as different as the earthworm and the dog have cells which are very similar in shape. Cells usually have different shapes according to the function they perform, and not according to the animal in which they occur. In general, this is true of plants also. *Exercises 11, 12.*

But differences in shape do not greatly affect the internal structure of cells. Almost all cells have the same general structure. (The exceptions are not important here.) As the figures show, there are three chief parts: there is a *cell body;* it contains a *nucleus* (new′clee-us) and is held together by a *cell membrane.* The cell body is made of protoplasm to which the special name *cytoplasm* has been given. The protoplasm of the nucleus is called *nucleoplasm.* The cell membrane is also made of cytoplasm, slightly thickened.

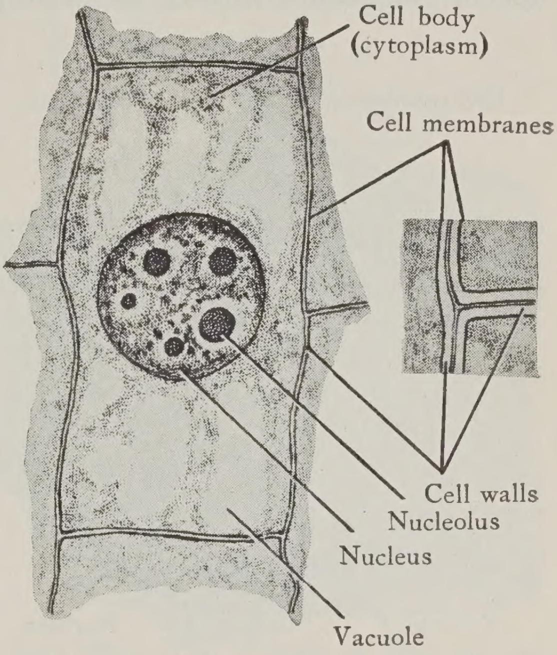


Fig. 359. A cell from the root-tip of a Tradescantia plant. What are the chief parts? Which parts are living; which are lifeless? Compare this diagram with the diagram of a "typical" animal cell.

There are other structures present in the cell. Many cells, especially plant cells, have a lifeless wall outside the cell membrane. These walls differ in different types of cells. In plants, they are made of *cellulose* or of a woody material made of cellulose and other substances. In animals, cell walls, if they are present, are made of a complex material called *chitin* (ky′tin). You are acquainted with chitin because your hair and nails are masses of the lifeless cell walls (chitin) of skin cells. Cell walls give support and protection to the cell body; they do not affect the passage of substances into or out of the protoplasm. It is the cell membrane which acts as the osmotic membrane.

Within the cytoplasm of the cell body are many structures, some of which play an important part in the life of the cell. The functions of some of these structures are familiar to you. You know that the *chloroplasts* are little bodies of protoplasm that build up carbohydrates. They are able to do this because they contain a special substance known as *chlorophyll.* The *vacuole* of the plant cell is usually filled with cell sap, a watery substance containing many materials dissolved in it. A few plant cells and most animal cells contain *centrosomes,* which play a part in the division of the cell. *Exercise 13.*

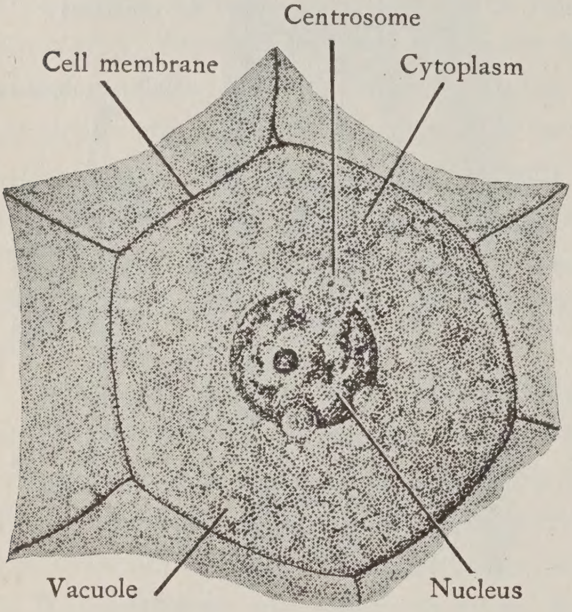


FIG. 360. A diagram of a "typical" or "average" animal cell. What structures are present that do not appear in the Tradescantia root cells? What parts, found in that plant cell, are absent from this one?

The structure of the nucleus of the cell. The nuclei of different types of cells are much more alike than are the cell bodies. Nuclei vary but little in shape and are almost exactly alike in internal structure. Every nucleus has a *nuclear membrane* which separates it from the cell body. Through it, as through the cell membrane, substances pass in and out by osmosis. The nucleoplasm, like all protoplasm, is a complex colloid. It consists of substances which differ in some ways from those in the surrounding cytoplasm.

But there is one striking material in the nucleus not found in the rest of the protoplasm. Sometimes it seems to take the form of a network; actually, it is present as scattered granules. During the life of the individual cell it even changes its shape, but in whatever shape it occurs it stains so deeply with certain kinds of dyes that it is easy to recognize. Because of the readiness with which it absorbs stains it was called *chromatin* (crome'a-tin). Because of the part it plays in the division of the nucleus and in reproduction it is undoubtedly a most important material in the cell.

Frequently a small round body is found within the nucleus. It is called the *nucleolus* (new-clee'o-lus). The nucleolus is not made of chromatin material at all but it takes some of the ordinary stains for chromatin, showing up clearly as a body even darker than the chromatin itself. Its function has not been definitely determined.

The work of cells. Since living things are made of cells the functions of living things must be performed by cells. When an animal eats it is taking in food for its cells; in time each living cell will take in food. When the animal breathes it obtains oxygen for its cells; that is, each cell eventually takes in oxygen. And each cell gives off carbon dioxide and water and other wastes which are then given off by the animal as a whole. In short, each living cell performs all the metabolic functions characteristic of the organism, each cell shows irritability and at least for part of its existence, it reproduces. This is true of plants as well as of animals.

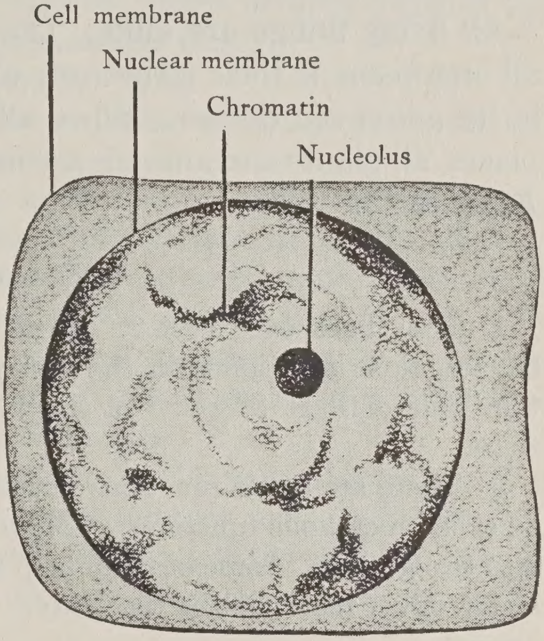


FIG. 361. The nucleus in this cell has been drawn large in order to show its parts. What else helps to make up the nucleus besides the parts labeled?

To be sure, besides this, some cells in a many-celled organism perform certain special functions more actively or more efficiently than do some of the other cells. Gland cells secrete more actively than do other cells; muscle cells contract more efficiently and nerve cells carry impulses faster. You know that there is differentiation in structure and specialization in function and that thus tissues arise in most many-celled animals and plants. But however specialized the tissue cell is, it must perform the basic activities (life functions) of living things. Even though it is a nerve cell, the cell must digest, secrete, oxidize, and so on.

This does not mean that each cell in a complex organism is a little living thing like a protozoan. Biologists no longer compare a tissue cell of the higher plants and animals with the individual protozoan or a single-celled plant. It is now recognized that the one-celled organism is far more complex than an ordinary cell. When making comparisons, therefore, the single-celled protozoan is considered the equivalent of the whole many-celled organism.

All living things are alike. One of the basic similarities among all organisms is their structure: all are made of cells. This similarity goes even deeper. Since all cells are small masses of protoplasm, all plants and animals are made of the same kind of material. *Exercise 14.*

Exercises

1. Look back over Part 2. Read the Unit questions. Which of the life functions mentioned in the first paragraph are described in each of the Units of Part 2? Give a simple explanation of each of these functions.

2. There are seven functions included under metabolism. These may be called metabolic functions. Can you see that they arrange themselves into two groups? Some of them help to build up the body; some of them break down materials in the body. Which would you include in each group?

3. *Demonstration.* Chaos chaos, a very large protozoan of the Ameba group, any large Ameba, or any slime mold may be demonstrated. What can protoplasm do? What are the properties of protoplasm? Touch it with a glass point. What properties does it show now?

4. If you will have an opportunity to use a school microscope you should be familiar with its parts. Starting at the bottom they are:

base
mirror
diaphragm attached to the bottom of the stage
stage (which holds the glass slide)
arm (the part by which you carry the microscope)
barrel (the thick vertical tube)
nosepiece (revolving part at the bottom of the barrel)
objectives (two lenses screwed into the nosepiece)
coarse adjustment (two large wheels on either side of the barrel)
fine adjustment (two smaller wheels). In older microscopes there is one horizontal wheel.
ocular or eyepiece (the lens fitted into the top of the barrel)

Examine the mirror. In which directions can it be moved? The flat surface is used for low-power work (the smaller magnification). What is the shape of the other surface? How do the two objectives differ from one another? The shorter one is the low-power objective. Examine the diaphragm carefully. How does it work? What is it for? Slowly turn the coarse adjustment, then the fine adjustment. What effect does each have on the barrel? If the microscope is placed before you so that the arm is toward you, how must you turn the wheels in order to move the barrel up? It is important that you remember this.

5. How to find an object under the low power.

(*a*) Place the microscope so that the pillar is toward you with the base resting firmly on the desk or table.

(*b*) Place the slide on the stage so that the material on the slide is over the hole in the stage. Hold the slide in place with the two clips.

(*c*) Turn the low-power objective (shorter one) until it clicks into place. It will then be exactly over the hole in the stage.

(*d*) With your eyes held at the level of the stage, *not at the ocular,* lower the barrel, using the coarse adjustment, until the tip of the low-power objective is about $\frac{1}{4}$ inch above the stage.

(*e*) With your eye at the eyepiece turn the mirror so that the flat side is up and secure the best uniform bright light by moving the mirror.

(*f*) Now, with your eye at the ocular, slowly raise the barrel by turning the coarse adjustment *toward you.* Do this until you can clearly see the material on the slide.

(*g*) You may have to move the slide to see some other part of the object (material).

(*h*) If the object is not as clear as it might be, turn the fine adjustment no more than half a revolution, now one way, now the other, to see whether you can focus more accurately. If you still do not get a satisfactory focus, try once more from the beginning, this time focusing more carefully with the coarse adjustment before using the fine adjustment.

6. To focus, using the high power.

(*a*) With the concave surface on top move the mirror until the best light is obtained.

(*b*) Focus carefully under the *low power.* Make sure that the object that you are looking at is in the *center* of the circle (field of vision).

(*c*) By grasping both objectives, slowly swing the high-power objective into position over the hole in the stage without shaking or moving the microscope.

(*d*) With your eye at the ocular, move the fine adjustment toward you slowly until the object becomes clear. Use only the *fine* adjustment. If instead of becoming clearer it becomes less clear, turn the fine adjustment the other way. But do not make more than one half revolution with the fine adjustment.

7. Study Ameba under the microscope so that you may become acquainted with the *structure* of protoplasm. Does the protoplasm look alike throughout? If you see differences describe them. What can you see in the clear outer layer? Does the protoplasm look to you as it looked to the early observers, a thickish liquid, grayish in color, containing small particles?

8. Make a starch paste in hot water. Compare it with a mixture of starch in cold water. What makes you think that the starch particles are suspended in the hot water and not dissolved?

9. In reading about cells and protoplasm you read the names of various scientists. While you may not remember each one's contribution it is important for you to realize that many, many scientists were working along the same lines before definite conclusions were reached. Can you cite other instances to show that this happens in science? Is it usual or unusual? Why is it important for a scientist to keep accurate notes and publish reports in scientific journals?

10. What is the difference between a theory and a doctrine?

11. Can you demonstrate by using the microscope, if possible, or by means of accurate drawings, that very different kinds of cells are found in one organism? Which cells will you choose?

12. How could you give a young child a clear idea of the shape of a cell? What would you use to demonstrate it? Do it.

13. If you have not already done them, do the exercises at the end of Problem 1, Unit I.

14. *Summary.* What truth is there in the statement that there is unity in all living things? Discuss this fully. In your discussion explain what new ideas you have gained about protoplasm. Make as complete a statement as you can of the modern Cell Doctrine.

Activities for the Junior Biologist

1. Read Huxley's lecture, "The Physical Basis of Life." Report to the class. If there are parts that seem to be particularly good summaries, read them to the class.

2. Biologists have succeeded in preparing imitations of protoplasm, using lifeless substances. Demonstrate to your class. (See Ponder's *Essentials of General Physiology,* or Bayliss's *Principles of General Physiology.*)

3. Learn how to use an oil immersion lens.

4. Prepare a report on the history of the microscope.

5. Demonstrate different kinds of colloids.

6. Locy's *Biology and Its Makers* has interesting material on the early history of the study of cells. Prepare a report. Singer's *History of Living Things* may be used, also.

7. Prepare charts to show different types of cells. If your diagrams are accurate, your chart may be accepted for use in class.

8. Prepare slides of stained cells. This takes great skill but if you are interested you can achieve splendid results. Use Guyer's *Animal Micrology* or similar books for suggestions. Your teacher will be able to help you, too.

9. *Demonstration.* If a binocular microscope is available, demonstrate its use for observation and dissection. Why is the compound microscope not suitable for dissection? How does the binocular microscope help the biologist to learn about the shapes and movements of organisms?

10. *Demonstration.* If a dark-field attachment is not available, the dark field may be demonstrated with the school microscope by turning the mirror suitably. Use the dark field with several organisms for which normal lighting has been used. Does the dark field change the image? Are any structures visible that could not be seen by ordinary methods? Use a very strong source of light. Is the dark-field image improved?

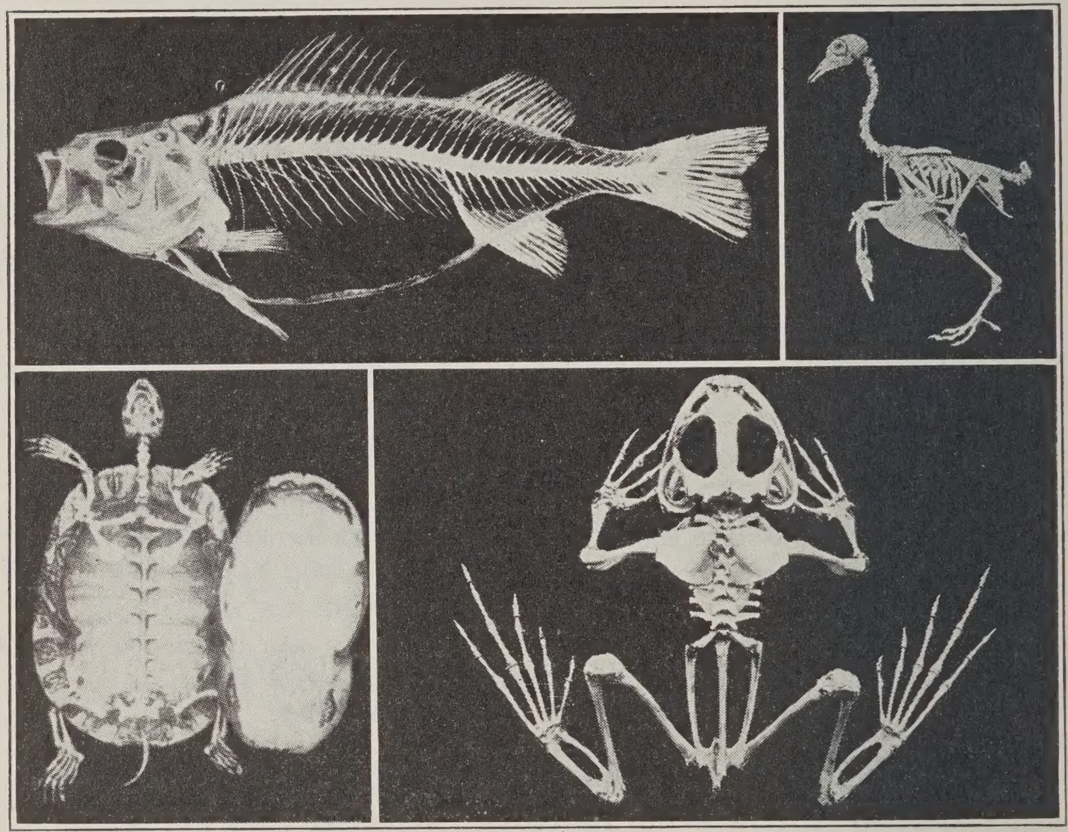
11. Suppose that you were a biologist who had determined to study a small organism, such as one of the Protozoa (Blepharisma, Stentor, Spirostomum). Describe the instruments you would use. What kind of information would you expect each instrument to supply?

2. Living Things Show Various Degrees of Resemblance to One Another

There are two main streams of life. All living things are basically alike in structure and function. Whether they are plants or animals, single-celled or many-celled, they are all made of living matter, protoplasm, and they all perform the same major life functions. Many-celled plants and animals have their cells arranged in tissues; that is, they show differentiation in structure and specialization in function. And the tissues, as you know, are found in groups making up organs, each of which performs some particular function for the organism as a whole. *Exercise 1.*

Among all animals, except the Protozoa and sponges, the same kinds of tissues are found. In all, there are groups of cells that are highly contractile; the animals all have muscle tissue. Somewhere in the body there are cells that have enormous powers of secretion; the animals have gland tissue. There are cells that have extreme irritability; the animals all have nerve tissue. Thus there is among all the many-celled animals a similarity beyond the basic similarity described in the last problem: they have the same kinds of tissues. (See the pictures in Unit I, Problem 1.) *Exercise 2.*

Among the many-celled plants there is a corresponding similarity. Certain tissues are found in many different kinds of plants; namely, those tissues that consist of tough fibers to give strength, those consisting of strong ducts, and those consisting of thin-walled cells with chlorophyll.



Ward's Natural Science Establishment

Fig. 362. Fish, bird, turtle, and frog. These animals all belong to the same phylum (vertebrata). What similarities in skeleton do you note besides those mentioned in the text?

But the tissues that appear so regularly in animals are not found in plants; and the fibers and ducts characteristic of the plant do not occur in animals. In other words, there are two main kinds of living things, animals and plants. While basically they are alike because all consist of protoplasm, every animal, except some of the Protozoa, has more in common with every other kind of animal than it has with any kind of plant. At first glance, the sea anemones and sponges may resemble water plants far more than they resemble insects and crabs. But closer examination of their tissues shows them to be like the tissues of other animals. *Exercise 3.*

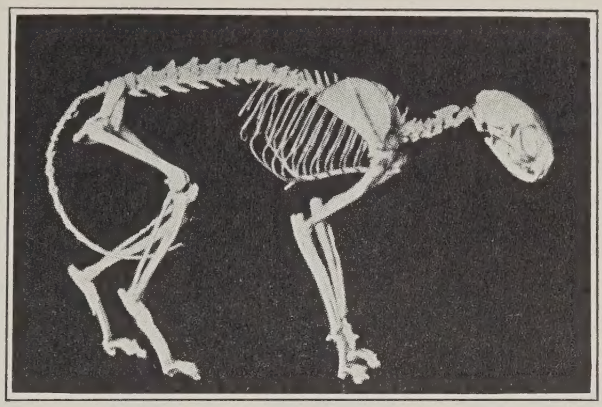


FIG. 363. The cat, a mammal, is also a vertebrate. How does its skeleton resemble those of the fish, bird, turtle, and frog?

Further resemblances among animals. Animals show wide differences in size, in shape, and in their habits. But closer study of their structure often shows unsuspected resemblances besides the similarity in tissues. For example, backboned animals that are quite different in outward appearance, the frog, the sparrow, the crocodile, the horse, the fish, and others you might name, are very similar in the structure of their skeletons. They all have a backbone; and this backbone is much the same in all. It consists in every case of similar bones (the *vertebrae*), each with a large hole through it. Attached to this backbone there are ribs, and there are other bones that are more or less like yours. *Exercise 4.*

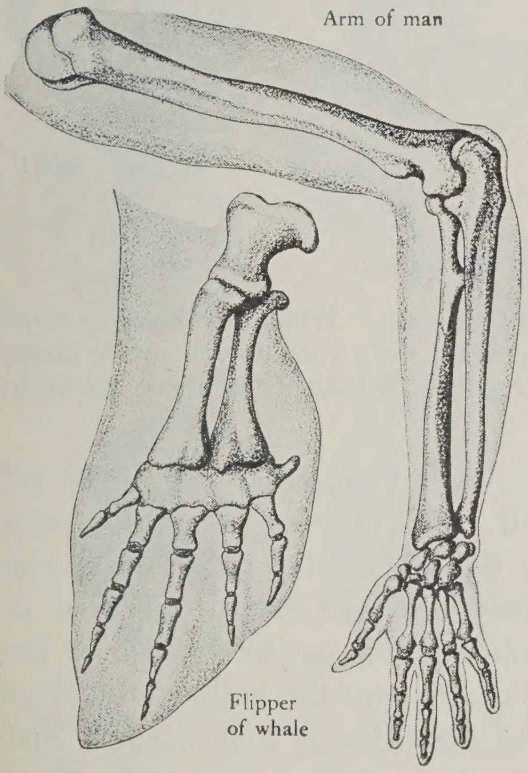


FIG. 364. Although the whale and man have different habits of life and are different in appearance, the bones of the whale's flipper are much like the bones of a man's arm. What resemblances do you find? How does this illustrate unity in living things?

Similarity in other organs and organ systems. You have read that the tissues of one animal resemble those of any other and that among certain animals of widely different size and form there are organs such as bones that are surprisingly alike. Comparison of animals shows them to be similar in other organs, too. A whole division of biology has grown up about the method of studying the structures of animals by comparing them. It is known as *comparative anatomy*, since anatomy is the study of the structure of an organism. One of the important discoveries made by comparative anatomists is that many vertebrates that are widely different in appearance and habits have various organs that are strikingly similar. *Exercise 5.*

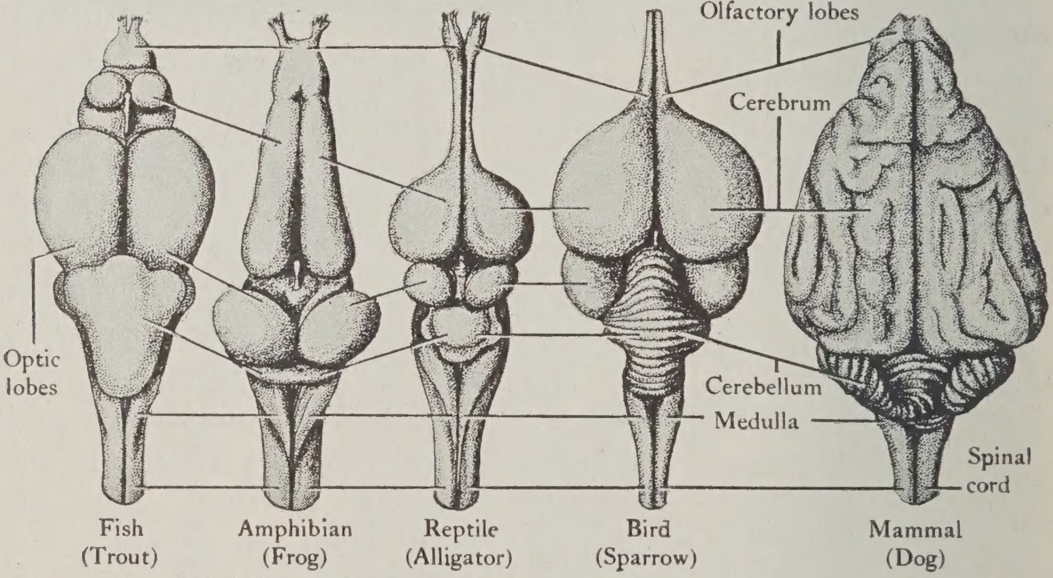


FIG. 365. Which parts do you find in all five brains? Which part does not show in the dog's brain? Differences are apparent. But what do you notice about the general plan? Compare the dog's brain with that of the sheep shown in Unit VI, Problem 5.

Similarity in embryos. All the higher animals and almost all others start life as a single egg cell. Cell division takes place and the mass of cells forms a hollow ball (blastula) and then a cup (gastrula). This occurs in all vertebrates and it happens, also, in much the same way in such simple animals as the starfish or the sea urchin. Then differentiation begins and the embryo develops a definite shape. Now the interesting thing is that when it first begins to take the shape of an animal, no matter whether it will in time become a fish, an amphibian, a reptile, a bird, or a mammal, its general appearance is much the same. The young embryos of many vertebrates look so much alike that you would find it hard to tell one from another. Even the older embryos show striking resemblances.

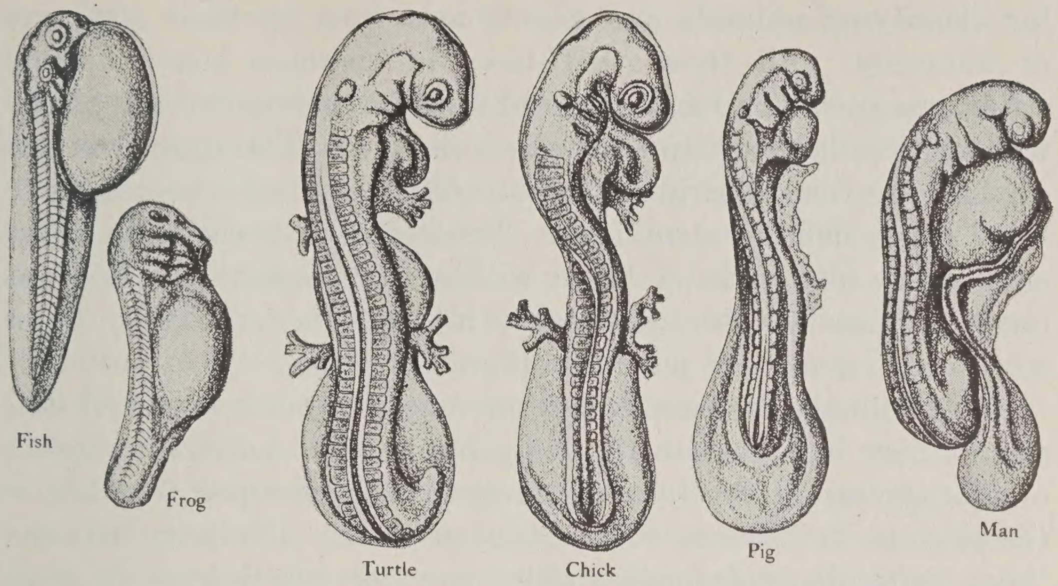


FIG. 366. In what ways are these early embryos alike? By what differences could you tell them apart?

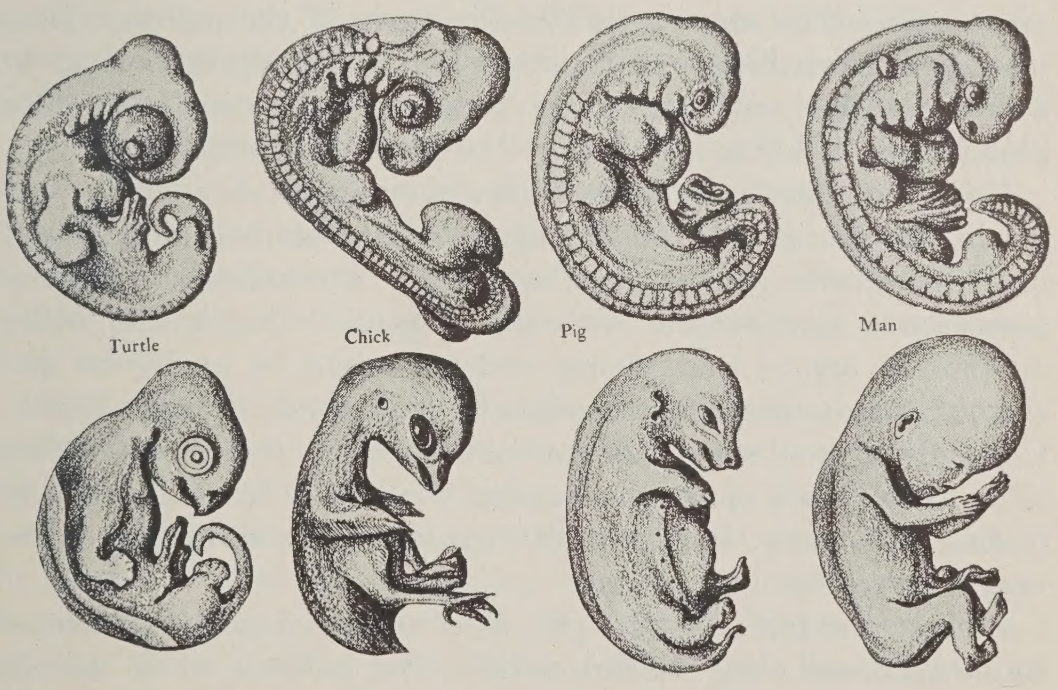


FIG. 367. This shows embryos in later stages. As differentiation goes on the embryo looks more and more like the adult. How do these diagrams illustrate unity among living things?

Resemblances and classification. What you have just read takes you back to one of the early chapters in the book, on the "Sorting of Animals and Plants." You read there how biologists, after many attempts at classification, finally settled on a scheme for classifying animals and plants according to their structure or anatomy. All those that have in common some striking structures such as a backbone and a hollow nerve cord are placed together in a large group known as a phylum. The animals of one phylum are then separated out into different classes according to some other definite structures. Those within a class are again subdivided into orders; those within each order into different families, those within each family into genera, and lastly those within each genus are put into different species.

Since animals are classified in this way it is to be expected that you can see likenesses in the bony framework and in some other organs among all the forms that are loosely grouped together in the phylum Vertebrata. There is even greater similarity between those particular vertebrates which are put together in the class Mammalia. For example, if you compare the brains of different forms you will find the brains of dog and sheep and man more like one another than any one is like the brain of the pigeon. Dog, man, and sheep belong to the same class; the pigeon belongs to a different class, although all of them are vertebrates. Another illustration of this is afforded by the picture of embryos above.

Now if you continued your studies of comparative anatomy you would discover an even greater likeness if the animals all belonged to the same order (such as the Carnivora). The animals within one genus have such similar skeletons, digestive tracts, and other systems of organs that young students might be unable to distinguish one animal from another from a study of these parts. Certainly, if you compared the animals of one species with those of another species of the same genus you might have difficulty in finding differences; in almost all their structures such animals are very much alike.

Animals are put into the same species when they show extreme similarity in all their characteristics. But animals which merely belong to the same phylum, while they resemble one another in many ways, have fewer structures in common so that in outward appearance they may be very different.

Thus you see that animals bear all degrees of resemblance to one another from extreme similarity to remote resemblance. If this were not the case biologists could not classify them as they do, first into large groups of widely different forms called phyla and then into narrower and narrower subdivisions ending with the species.

Chemical resemblances. Just as animals show unexpected structural resemblances so do they show chemical resemblances. Of course you know that there is a certain chemical similarity among all organisms. This grows out of the fact that living things are made of protoplasm, which is much the same in animals and plants. But there are further chemical resemblances between organisms grouped together.

As you know, human blood corpuscles contain a substance called hemoglobin that is able to unite loosely with oxygen. All other members of the vertebrate phylum are like man in having hemoglobin in blood cells. The crayfish (an invertebrate) contains in its blood a chemical substance related to hemoglobin but different from it. This substance (hemocyanin) also has the power of uniting loosely with oxygen so that the colorless blood turns blue on exposure to air. There are other invertebrates with similar substances in their blood. A few even have hemoglobin in their blood, but it is dissolved in the plasma, not found in blood cells.

In plants there may also be chemical similarities. Sometimes plants which have been put into the same family because of similar structures, prove upon experimentation to be similar in their chemical composition too. For example, lemons, oranges, limes, and structurally similar plants are chemically alike in containing citric acid.

More delicate tests show varying degrees of chemical resemblances. In an earlier unit you read that when certain proteins are injected into the blood of an animal, the cells of the animal will produce antibodies. Some of these antibodies cause the protein to come out of solution; that is, the dissolved particles of protein clump together until they can no longer remain in solution. This is called *precipitation.* When this takes place in a test tube the precipitate shows as a mass of solid particles that tend to settle. For example, the rabbit forms antibodies in its blood against horse serum which is injected into it. If later some of this rabbit's blood (containing antibodies) is mixed with fresh horse serum in a test tube a visible precipitate will form and the amount of this precipitate can be measured. If now serum from an animal similar in structure to a horse is used with the rabbit serum the amount of precipitate is smaller. If the animal is widely different the amount of precipitate is smaller still or no precipitate forms at all. In other words experiments show that the chemical resemblances vary just as the structural resemblances do. *Exercises 7, 8.*

Recently, plants have been used in similar experiments. The plant protein is used in place of blood. As in the case of animals, the chemical resemblances closely follow structural resemblances.

While there is a basic similarity between all animals and plants, there are many minor resemblances which vary in degree. Biologists have made use of this by constructing a classification that indicates varying degrees of resemblance. The closer animals and plants are in the Linnaean scheme of classification, the greater is the resemblance, both structural and chemical. *Exercises 9, 10.*

Exercises

1. Do different kinds of animals have different kinds of tissue cells? Examine striated (voluntary) muscle cells of several animals, both vertebrate and invertebrate. Can you distinguish cat striated muscle from insect muscle? Examine other types of tissue cells, taken from various animals. How successful are you in telling these apart? Answer the exercise question in a paragraph.

2. Do different kinds of plants have different kinds of tissue cells? Examine cross sections of roots, stems, and leaves of various plants. Can you find similar cells in the sections of leaves? of roots? of stems? Draw diagrams to show types of plant tissue cells.

3. Do plants and animals have the same kinds of cells? Are there any plant cells that have the shape of nerve cells? of muscle cells? of skin cells? of cartilage cells? Do plant and animal cells that resemble one another have the same functions? Give reasons for your answer. Write a paragraph comparing plant and animal cells in general.

4. In what ways are some of the vertebrate skeletons alike? In what ways different? Study the skeletons of the frog, the reptile, and the bird. How are the hind legs attached in each case? The ribs are attached to the vertebrae; to what are they attached at the other end? Note the shape of the bird's breastbone. How does it differ from the breastbones of other vertebrates? What other resemblances and differences do you note in these skeletons? When you find differences can you see an advantage to the animal in each case?

5. How do the internal organs of vertebrates resemble one another and differ? Use museum preparations, dissections, models, charts, or the pictures in the text.

(*a*) Brain: How are the brains alike? how different? Which is the most complex? In which ways is it more complex?

(*b*) Digestive systems: Can you describe the similarities in the digestive systems?

6. What resemblances are shown by the embryos of vertebrates? Use museum preparations, models, charts, and pictures. To which class does each embryo belong? In what kind of environment does each embryo spend the early part of its life? What surprising structures do you find in some of these embryos? Which structures appear first? Which structures change last? Among which embryos do you find the greatest degree of resemblance? Sum up your observations.

7. What is meant by precipitation? You can see a simple precipitation by adding some silver nitrate solution to a test tube containing some sodium chloride (table salt) solution.

8. Suppose a rabbit had formed antibodies against police dog serum so that a precipitate would be formed when the blood of the two animals was mixed in a test tube again. If you mixed blood from the following animals with rabbit serum, which should form the largest precipitate, which next, and so on to the smallest: spaniel, fox, wolf, cat, robin, crocodile, trout, and toad?

9. *Summary.* What important new ideas have you learned from studying this problem? List them.

10. *Unit Summary.* The unit title states that there is unity in all living things. Tell (*a*) what this statement means, (*b*) why the biologist considers it a true statement, (*c*) why it is an important idea.

Activities for the Junior Biologist

1. Can you plan and make a large chart showing in how many ways man is like other organisms? Consider cells, tissues, organs (including bones), and functions.

2. Does man resemble any other organisms in his ways of living? (*Hint:* Study the social life of insects and the groupings of wild horses, etc.) Report to the class.

3. If you are good at using clay prepare a series of models showing vertebrate embryos at various stages. If you use several colors you can show similar organs and how they change.

4. Prepare a report on the life of Linnaeus. Donald Culross Peattie's book, *Green Laurels*, is an interesting source of information.

5. Haeckel, a German biologist, once proposed that all living things be divided into three groups: Plants, Animals, and Protista (one-celled organisms of all kinds). A small committee of pupils might prepare a discussion of the advantages and disadvantages of this classification. (Do not debate; scientists do not. Study the subject, talk it over among yourselves so that you understand it, and then discuss it before the class. Do not prepare your speeches; prepare the subject!)

Good Books to Read

Bausch and Lomb Optical Company, *The Use and Care of the Microscope.* Rochester, N. Y.
Beavis, G., *The Book of the Microscope.* Lippincott.
Calkins, G. N., *The Smallest Living Things.* University Society.
Clark, C. H., *Practical Methods in Microscopy.* Heath.
De Kruif, P. H., *Microbe Hunters.* Harcourt, Brace.
Disraeli, R., *Seeing the Unseen.* Reynal and Hitchcock.
Ealand, C., *The Romance of the Microscope.* Lippincott.
Eastman Kodak Company, *Photomicrography.* Rochester, N. Y.
Fasten, N., *Origin through Evolution.* Knopf.
Fox, H. M., *Biology, an Introduction to the Study of Life.* Macmillan.
Hegner, R. W., *College Zoology.* Macmillan.
Locy, W. A., *Biology and Its Makers.* Holt.
Neill, R. M., *Microscopy in the Service of Man.* Holt.
Sharp, L. W., *Cytology.* McGraw-Hill.
Shipley, A. E., *Hunting under the Microscope.* Macmillan.
Singer, C., *The Story of Living Things.* Harpers.
Sinnott, E. W., *Botany.* McGraw-Hill.
Spencer Lens Company, *The Microscope.* Rochester, N. Y.
Stokes, A. C., *Aquatic Microscopy.* Wiley.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.

UNIT XI. THERE IS A BALANCE OF LIFE ON THIS PLANET

1. The Repeated Use of Earth Materials Makes Possible the Continued Existence of Plants and Animals
2. Within a Small Area Temporary Shifts in Balance Are the Rule; Normally They Right Themselves
3. Man Tends to Disturb the Balance of Life
4. Man Is Beginning to Understand and Control Plant-Animal Relationships

1. The Repeated Use of Earth Materials Makes Possible the Continued Existence of Plants and Animals

Plants and animals have been drawing on earth materials for countless ages. All living things are made of protoplasm. This protoplasm is fundamentally the same in all of them; it is a complex mixture (colloid) of many substances, some very complex. There are certain elements which always go to make it up: carbon, oyxgen, hydrogen, nitrogen, sulphur, phosphorus, and some others. Unless protoplasm obtains these elements it cannot build more of itself. And as long as the protoplasm is alive it releases energy. To do this it must be supplied with free oxygen. The world over, wherever there are living things, the same elements are in demand for assimilation and respiration. These elements must, of course, come from the earth and air and water which make up our planet. That is why they are spoken of as earth materials.

But you already know that most elements cannot be used by living things unless they are chemically tied up with other elements. The most important exception is oxygen, which is used in oxidation. But for food manufacture, plants always get the necessary elements out of simple compounds, carbon from carbon dioxide, hydrogen and oxygen from water. Nitrogen, too, can be used by the green plant for the making of protein only if it is united with oxygen and other elements in nitrates. And animals obtain their necessary elements in even more complex compounds, the carbohydrates, fats, and proteins. Thus when you read that certain elements are needed as food you must understand that it is really the simple compounds of our planet which are being drawn upon.

Now such earth materials have been taken in by organisms for countless ages. Scientists are convinced that for more than a billion years there have been living things using oxygen for oxidation and using simple compounds for making protoplasm of the same general kind as exists today. Yet the supply of these earth materials has not been used up!

Why earth materials are not used up. The way to make a limited supply of anything go a long way is to use it over and over again. The United States Treasury puts a large number of bills into circulation. If everyone sewed up the bills in bags as fast as they came into his possession, there would soon be a shortage of bills in spite of the large number. But if you give a bill to the grocer and he passes it on to the automobile dealer and from there it goes to the butcher the one bill does the work of three. Every time it changes hands it does its work over again. In the same way the little particles (molecules) of the elements can be used first by one organism, passed on to a second, and to a third or back again to the first organism. Bills, being made of paper, cannot be circulated forever because they wear out. But chemical elements are different; no matter how many times they are used they do not wear out or get lost. You will read that plants and animals are constructed in such a way that the one can use the substances given to it by the other. For this reason earth materials have not become exhausted (used up).

How some of the necessary elements are kept in circulation. The green plant uses carbon dioxide for making carbohydrates. A small amount of the carbohydrate is oxidized, much of it is stored, and some of it is built up into proteins and fats. In other words, carbon dioxide is constantly being taken out of the air in large amounts and the precious carbon is being tied up or "frozen" in carbohydrates or proteins or fats. If there were only green plants in the world the available carbon would have become exhausted long ago. But there are animals, too. They eat the plant and take the various carbon compounds (the carbohydrates, the fats, and proteins) into their bodies. At first glance this does not seem to help matters much. Whether carbon is sealed up within the body of the plant or of the animal seems to be of little importance; in either case it has been taken out of circulation. But there is this great difference between plants and animals: animals, for the most part, move about; they are active; oxidation within their cells is constant and rapid. Much of the carbon they obtain from the plants that they eat is oxidized. At times in some animals, it is true, large amounts of carbon are stored in the form of fats. But this is usually temporary. When the carbon is oxidized the carbon unites with oxygen to form carbon dioxide. This is released into the air and thus carbon is put back into circulation. It can be used again by the plant. Of course, the plant also carries on oxidation but the process is so slow that it is of little importance in restoring carbon (in the form of carbon dioxide) to the air.

What is true of carbon is equally true of hydrogen. Combined with oxygen in water it is constantly entering the plant; there it too becomes tied up in carbohydrates, fats, or proteins. When oxidation occurs in the animal, and to a slight extent in the plant, the hydrogen combines with oxygen and is restored to the earth in the form of water. The same hydrogen can thus be used over and over again.

How oxygen can be used again and again. You read that the high rate of oxidation which is so characteristic of most animals puts carbon and hydrogen back into circulation; that is, it makes these substances available once more to plants. But in all this oxidation oxygen is used; it is taken out of the air and tied up in compounds, largely carbon dioxide. It would seem as if the amount of oxygen must grow smaller; but no shortage occurs. The green plant absorbs carbon dioxide, breaks it up into its elements, uses the carbon, and gives off the oxygen as a waste product. Thus three important elements of protoplasm, carbon, hydrogen, and oxygen, are always being used over and over again. This is possible because plants and animals perform their activities in such a way that each helps the other. *Exercises 1, 2, 3.*

How nitrogen becomes tied up. To manufacture its proteins the plant absorbs such simple compounds as potassium nitrate or sodium nitrate from the soil. Day after day and year after year these compounds are removed from the soil, and their nitrogen becomes tied up in a vastly more complex compound, protein. The proteins are assimilated into the protoplasm. The plant grows and reproduces. It is eaten by animals and changed into animal protoplasm; the nitrogen still remains tied up. This has been going on for many millions of years, yet there are still nitrates in the soil. Why?

How nitrates are restored to the soil. Proteins are oxidized in the animal. Their oxidation results in the making of urea and other substances which are relatively complex nitrogen compounds. The animal excretes the urea and other nitrogen compounds and thus they find their way into the soil and water. But neither the animal nor the green plant can use such compounds. The nitrogen, therefore, still remains tied up.

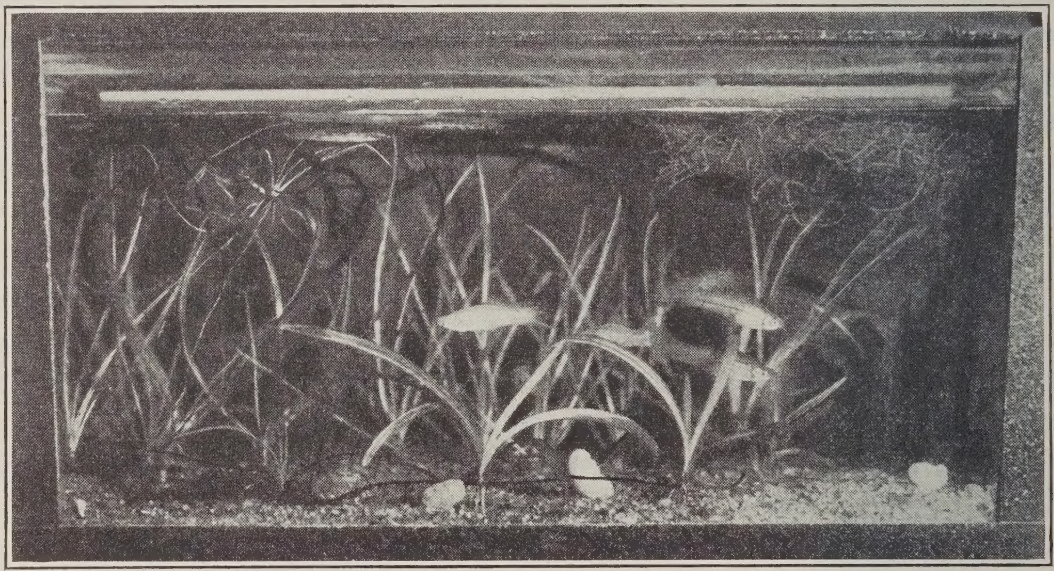


Photo by H. Schneider

Fig. 368. A tiny world of living things. What kinds of animals do you see? What substances do they get from the plants? What do they give the plants? Under what conditions can this aquarium be sealed?

There are bacteria living in the soil which can break down these nitrogen compounds still farther into ammonia and related substances. A similar process takes place when a plant or animal dies. Vast stores of nitrogen in the form of proteins are locked up in these dead bodies. Various species of bacteria begin work on them, making simpler compounds out of the proteins. These processes are called decay. In time, the various bacteria will have broken down the dead bodies into simple ammonium compounds which find their way into the soil. Nitrates are being taken out of the soil by the green plant and ammonium compounds are being put in by bacteria. At this rate nitrates would have been exhausted long ago and all life on this planet would have ceased were there not a way of restoring nitrates to the soil. This is done by various bacterial inhabitants of the earth which build up ammonium compounds into nitrates. They are called *nitrifying* (ny′tri-fy-ing) bacteria.

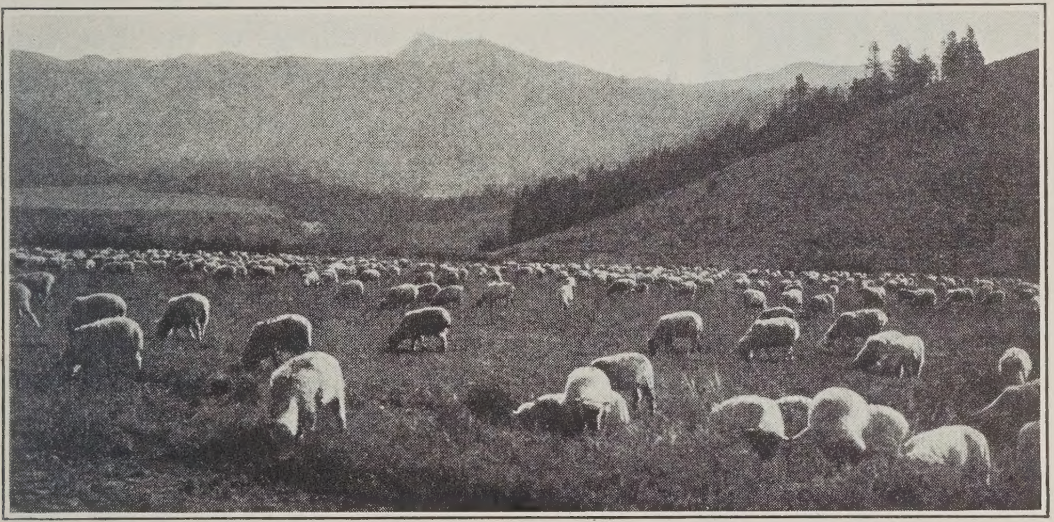
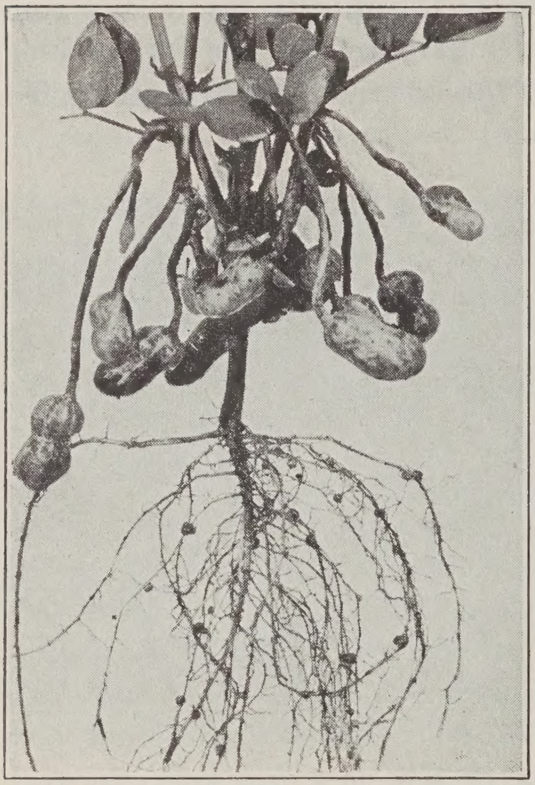


Photo U. S. Forest Service

FIG. 369. Chemical changes are going on here on a vast scale. In what compounds is nitrogen in the soil? In the plants? In the sheep?

Leakage of nitrates. Side by side with the nitrifying bacteria are other species known as *denitrifying* which again break down the nitrates to ammonium compounds. Depending on the particular conditions in the soil there is a constant breaking down or building up of nitrates. But among the denitrifying bacteria there are some that break down the nitrates completely, forming free nitrogen which passes off into the air as a gas. Since the element nitrogen cannot be used by green plants for food manufacture, nitrogen would seem to be lost to the world of green plants and indirectly to animals. There is thus serious leakage of nitrates.

Other kinds of bacteria come to the rescue. Fortunately, there are still different species of bacteria in the soil which have the power of using the gas nitrogen to build up nitrates. In their activities these bacteria are quite the opposite of the decay and denitrifying bacteria. Since they utilize free nitrogen and fix it in the form of nitrates they are well named *nitrogen-fixing* bacteria. Some of them live independently but others find their way into the roots of plants. Only some plants will serve; chief among them are beans, peas, clovers, or one of the other species belonging to this family (leguminous plants) whose roots frequently contain these bacteria. Once inside, the bacteria stimulate the root to form more tissue so that little swellings or nodules can be seen. Within these the bacteria live and do their work of construction, piling up nitrates. They do no harm to the plant in which they live; in fact, they supply this plant with its much needed nitrates. But the bacteria build up far more nitrates than the plant can use. Long before anything was understood about bacteria and nitrogen fixing it was known that planting clover or certain other leguminous plants improved the soil. *Exercise 4.*



Courtesy Brooklyn Botanic Garden

FIG. 370. Peanut plant with its strange fruits that develop underground. These roots show only a few nodules. How might the bacteria in the nodules profit by their position?

Through the action of the nitrogen-fixing and nitrifying bacteria the supply of nitrates in the soil is kept constant under natural conditions. However, where the land is planted with crops that are regularly harvested and where the farmer expects a large yield year after year, the soil bacteria are not given enough time for the large amount of work to be done by them; in that case the soil loses its supply of mineral substances unless man takes steps to prevent the exhaustion of the soil. *Exercise 5.*

Man's efforts to restore fertility to the soil. Not only did the farmer learn long ago that if he plants clover as one of his crops once in four or five years his other crops will be improved, but he learned that if he allowed his land to lie *fallow* (remain unplanted) for a year, it would improve. He has also known for a long time that turning up the soil frequently improves the crops. The explanations for these facts are not far to seek. When land lies fallow the constructive soil bacteria are given time to do their useful work. And since the bacteria need oxygen and nitrogen to build up nitrates the soil must be turned up so that air may become more thoroughly mixed with it.

Within recent years man has learned to raise the useful soil bacteria in the laboratory. They may be obtained from State Agricultural Stations or from the United States Department of Agriculture. The farmer inoculates his seed with these cultures before he plants. Man has learned, too, to make nitrates from the free nitrogen of the air by various processes. Large factories make nitrogen compounds to be sold as fertilizer to farmers. Man can also obtain nitrates from the huge natural deposits of nitrates in certain parts of the world, especially in Chile. But since this supply cannot renew itself it would soon become exhausted if man were forced to depend on it alone.

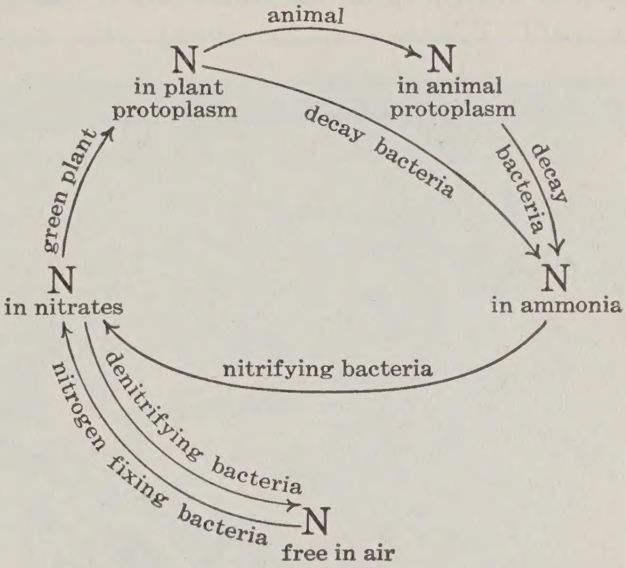
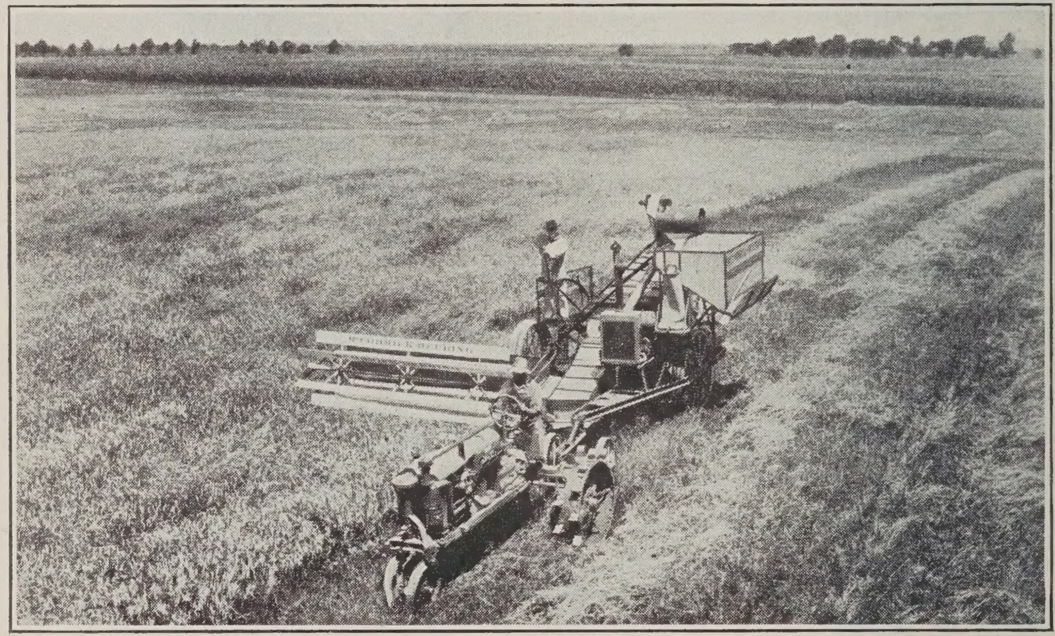


FIG. 371. The nitrogen cycle. The same atom of nitrogen is found now in one compound, now in another. The text explains the order in which changes occur.

There are other steps man takes to restore fertility to the soil which is used year in and year out for raising crops. To provide nitrogen compounds he mixes decaying substances with the soil. He can use the decaying excretions of animals, known as manure; or, if fish are plentiful, he can scatter fish on his land to decay and fertilize the soil. Vast deposits of bird manure are found on the uninhabited islands off the southern coast of Peru. These have long been the homes of vast flocks of birds (cormorants). It is said that on one island the number of birds is so great that their daily requirement of food is a thousand tons of fish! For countless years the excretions of these birds have accumulated and formed the vast *guano* (gwa′no) beds, so valuable as fertilizer.

There are other minerals needed by plants for making protoplasm. These, like the nitrates, are lost to the soil when the animal eats the plant. They, too, must be restored if life on this planet is to continue. However, they form a much smaller percentage of living matter and do not tend to be used up so quickly; therefore restoring them is not so great a problem. But the farmer takes this problem into account when he puts commercial fertilizer and lime on his soil. This restores the necessary phosphorus, potassium, and calcium compounds, as well as nitrogen.



Courtesy International Harvester Company

FIG. 372. Every year 60 pounds of nitrogen compounds are lost from each acre of cultivated soil. These fields extend for miles and miles. Why is the loss to the soil greater in cultivated than in uncultivated land?

Different types of living things make possible the repeated use of earth materials. The green plant builds up foods; it builds up far faster than it tears down. The animal depends on the plant for its food and is destructive in its activities. But you saw that its destructiveness is as important to the continuance of life as the constructiveness of the green plant.

However, the animal is not thorough enough in its destructiveness. It destroys carbohydrates but does not completely destroy proteins. There are decay bacteria, fungi of many species, that do the job of breaking down proteins. And there are other bacteria that break down organic matter into elements which are of no further use to living things.

But there are some species of bacteria which do not destroy; quite the opposite, they take the first steps in construction. They build some elements into simple compounds which serve the plant as food. This first step cannot be taken by green plants, which are in general the great constructive agents of the world. Thus by having different types of organisms, each with its own kind of activity, the planet's limited materials can be used indefinitely. *Exercise 6.*

Exercises

1. Draw a circle and by writing words and drawing pictures on the line show how carbon goes from the air through the seeds of plants into a bird, and back again into the air. This is called a *carbon cycle.*

Show how carbon goes from the air into grass and into a pig where large amounts are stored.

2. A grass plant absorbs CO_2 and changes it into protoplasm. How many organisms can you name through which, in turn, the same carbon may pass?

3. Draw an oxygen cycle.

4. Study the nitrogen "cycle." In what substances is N found? Which organism brings about the change in each case? Which organism releases the element nitrogen?

5. (*a*) Where would you expect to find the most fertile soil, in a forest or on the plains? Why?

(*b*) If you bought an old farm and the land was poor, what crop would you plant first?

(*c*) Explain how the same bacteria of decay may be useful in one place and harmful in another.

6. *Summary.* The last paragraph is a bare outline. Can you fill in the necessary facts to make a complete story?

Activities for the Junior Biologist

1. Can you devise experiments to show that plants and animals differ in the amount of their destructive activity?

2. You could demonstrate the usefulness of soil bacteria by writing to your State Experiment Station for some. How would you perform the experiment? For a control, how could you rid some soil of its bacteria?

3. Are bacteria more numerous in sand or in humus (the dark top soil from the woods)? If you have petri dishes, can you find out?

4. Start and maintain a balanced aquarium. Turtox leaflets should be of help.

5. If you draw well you could make interesting and original charts to illustrate the carbon, oxygen, and nitrogen cycles.

6. If you live near a farming section find out what the farmers are doing to keep the necessary soil compounds from becoming exhausted.

7. Read up about commercial, large-scale nitrogen fixation and report.

8. Cut open and examine a nodule on a fresh leguminous plant. Use a microscope. Try raising the bacteria.

2. Within a Small Area Temporary Shifts in Balance Are the Rule; Normally They Right Themselves

Relationships within small areas. Looked at as a whole the organisms of this world form a biological partnership. The activities of each organism make possible the activities of others. And so life has gone on for many millions of years. But if you look more closely at any fairly small area of the earth you soon discover that there are many kinds of partnerships among organisms.

You may recall the descriptions, earlier in the book, of life in the desert or in the tidal zone of the shore. The organisms in these places make up communities in which each species is more or less necessary to the group. Some provide others with shelter; some are used as food; some make changes in the soil that are useful to other organisms. Each species has a place because its activities make it useful to others; each finds some of the other organisms useful to it.

The ways in which the plants and animals of such a community affect one another are so complicated that they are extremely hard to study. The relationships form a tangle that one biologist has called "the web of life."

Biologists are just beginning to untangle this web in the small biological communities in which its study is easiest. The name given to this special study of the relationships among living things and their relationship to the environment is *ecology* (ee-kol′o-gee). Ecology is one of the most recent subdivisions of biology.

Food chains. Study the activities of organisms and you will find, with a few exceptions, that each organism is a member of a one-sided relationship that is not a partnership but a destructive relationship. Some organisms will be the destroyers, others will be the victims. In this relationship, the activities of one species lead directly to the injury of another. The need of the lion for food brings disaster to the antelope which makes its unsuspecting way to the water hole. The antelope destroys plants when it crops grass and the leaves of woody plants.

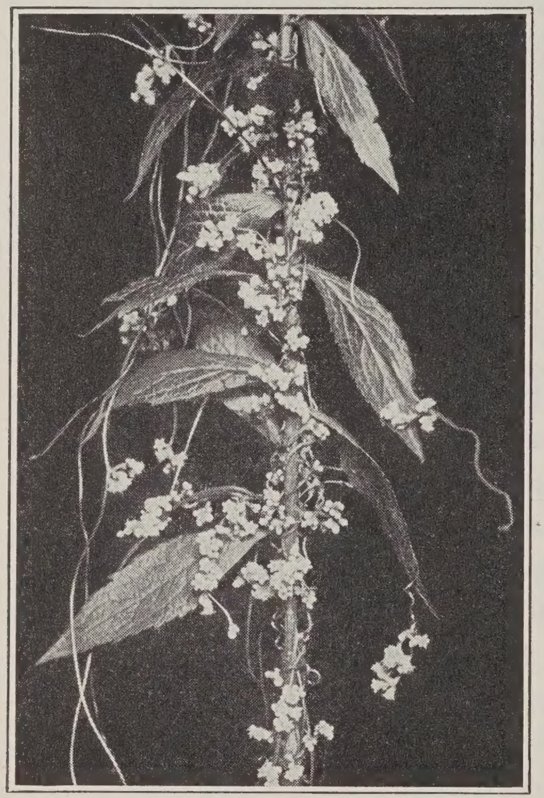
When the scene shifts from the African plain to a California orchard you can find scale insects sucking juices from the orange trees. And as the scales grow and multiply they make a meal for the ladybird beetles which soon may find their way into the crop of a kingbird. The bird, in turn, may provide a meal for a cat or a hawk.

In the surface waters of the sea float microscopic green plants known as diatoms (see Part 1). They are present in countless numbers. Darting through the same waters are water fleas (copepods), tiny animals, continually driving the diatom-laden water into their bodies. The tiny water fleas serve as food for larger invertebrates or for small fish, which in turn make good eating for the hungry herring or the mackerel.

In each case these living things are bound together by a one-sided relationship in which one organism destroys the other. It is a common type of relationship based entirely on the necessity for food. Since in this relationship each organism depends on another, forming a chain, the relationship is called a *food chain.* Sometimes the chain has many links, sometimes few. But in every case it has a green plant at one end, since the green plant manufactures the nutrients and is the original source of food. At the other end is some dominant animal. *Exercises 1, 2.*

Evidently, the organisms at the beginning of the chain are smaller and if the chain is to remain unbroken, they must be much more numerous than those at the end. While ten shrimp make a good meal for a herring, it takes many water fleas to feed even one shrimp, and numberless diatoms to feed one water flea. This must be true of every food chain.

A more intimate relationship. In the ordinary food chain the dominant animal is either larger or fiercer than the organism below it. But smaller organisms sometimes dominate larger ones. This occurs when, in its search for food, the smaller fastens itself to the larger organism. Since it feeds on the living tissues of the larger animal, it almost always brings disaster, more or less gradually, to the form on which it feeds. This intimate relationship is called *parasitism;* the victim is called the *host;* the organism that feeds on the living cells of the host is called the *parasite.*



© *P. Blakiston's Son & Co., Inc.*

FIG. 373. The dodder, of which you see stems and flowers, is growing on a goldenrod plant. It sends special roots into the stem of its host. Why does the dodder not need leaves?

You have read of parasites before and you know that man is a host to many; among others, the tapeworm, the hookworm, the malaria plasmodium, the fungus that lives in the human skin and gives rise to ringworm, the fungus that causes athlete's foot, and last, but most important, many species of bacteria. This incomplete list shows that a parasite may be either a plant or an animal and that there are parasites in a variety of plant and animal groups (phyla).

It is not only man and other animals that serve as hosts. Plants, too, have their parasites, both small and large. A plant may be attacked by a microscopic fungus or by some other complex plant which equals it in size.

The parasite is usually the last link in the food chain. Sometimes, it is true, the host successfully withstands the attack and provides food and shelter over a long period of time, eventually falling prey to some other organism. More often the parasite kills its host and by so doing it ends its own food supply.

Although the parasite depends on living tissues, parasitism is really much like the relationship between a larger animal and its prey or like the relationship between animal and plant. Man slaughters the sheep for food; the sheep crops grass and kills the plant; for the same reason, the parasite consumes its host. It is unimportant whether the victim is larger or smaller than the organism to which it supplies food. *Exercise 3.*

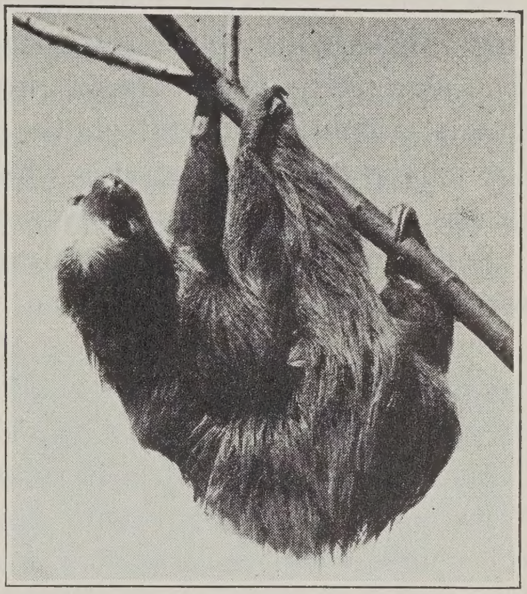


Photo by Hugh S. Davis

FIG. 374. Certain species of sloth have formed a partnership with a tiny alga which lives in the hair. What advantage does each organism gain?

Intimate relationships of benefit to both organisms. Within the intestine of the termite live protozoa of a special kind. They cannot live a free existence; they need the food and the conditions supplied by the digestive tract of this particular insect. But they are not parasites for they pay well for their housing. They break down and digest the wood on which the termite feeds. If the protozoa are removed the termite dies of starvation in the midst of plenty. In much the same way certain species of bacteria dwell within the shelter of the intestine of the horse, helping it to digest its food. Hay, like all plant food, has cells with thick cellulose walls. These must be dissolved away before the nutritious protoplasmic material within can be used. The bacteria do this valuable work for the horse. Such a relationship of mutual helpfulness between the members of two species is called *symbiosis* (sim-by′o-sis). There are many well known examples, in some of which the organisms living together (symbionts) form most surprising partnerships.

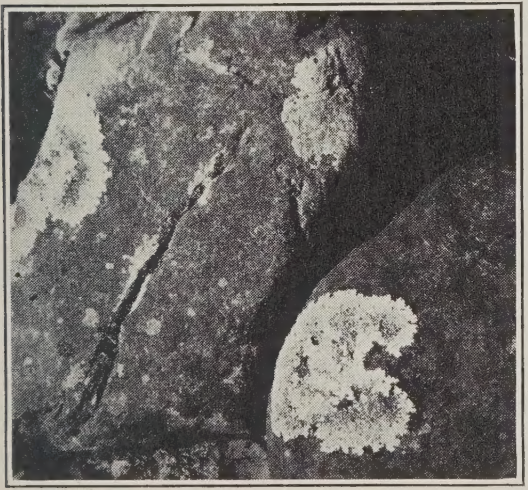


Photo by H. Schneider and J. Schwartz

FIG. 375. A common gray-green lichen, which grows flat on a rock.

Two plants may live together, too, each aiding the other. The best known case is that of the lichen (ly′kin). A lichen is not a single plant; it is two plants, so intimately bound together that this fact was not discovered until the middle of the last century. Tangled up in the threads of a fungus are the cells of an alga. The alga, by photosynthesis, provides the fungus with food; the fungus supports and protects the green plant. You read recently of the nitrogen-fixing bacteria which live in the roots of various plants. This too is probably a case of symbiosis. *Exercise 4.*

Sometimes when two organisms of different species live in intimate relationship it is difficult for the biologist to determine whether the relationship is one of parasitism or symbiosis. There are all degrees of helpfulness and harmfulness so that the one condition shades gradually into the other.

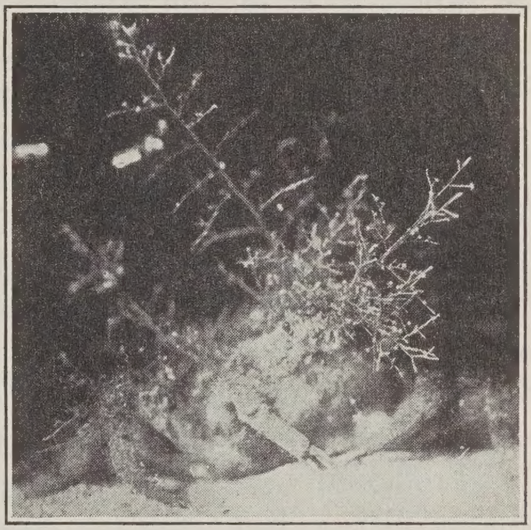
Each slight disturbance in relationship has far-reaching effects. With every organism tied up closely or distantly with others and those again touching upon the lives of still different ones, life becomes a tangled web of relationships. In this web each change or disturbance, no matter how slight, affects many other organisms.

In some summers the number of diatoms in the ocean is comparatively small. This change has the most far-reaching effect on the organisms that are linked with the diatom. Since small shrimp and other small animals feed on the diatoms they, too, will not be able to increase normally. In turn, the larger arthropods and small fish will be short of food. Because of this, fewer mackerel and herring will find food, so that, a year later, when the fishing boats follow the schools of fish in northern waters their catch will be smaller than usual and the price of herring and mackerel will rise because the catch is small. The reduction in the number of diatoms, the cause of which is not well understood, has an effect on all the other organisms in the chain, including man.

Changes in balance occur frequently; normally they right themselves. At each link of the chain described above a change in balance occurred. First, as the diatoms decrease there are too many shrimp for the small number of diatoms. When the shrimp die off, the balance between them and the next larger animal is changed and so on along the chain.

There is a dramatic example of a fairly regular change in balance that has attracted attention for hundreds of years. It grows out of the behavior of the lemming, a little rodent, much like the rat, that lives in the fields of the Scandinavian mountains. Every few years the rate of reproduction of the lemming increases, for reasons not yet understood. The next year or the year after, when there is no longer a proper balance between lemmings and the food supply, they migrate to the lowlands in hordes. Millions die on the way. Many millions continue to march across the land, swimming rivers wherever necessary, until they reach the ocean. They plunge in, continue to swim westward and perish when they can no longer remain afloat. Lack of proper balance between the lemming and its food supply is quickly righted by the animal's curious behavior. The causes of this behavior are not understood.

In other cases, the way in which lack of balance rights itself is easier to understand. The rate of reproduction of the rabbit, like that of the lemming, varies. In the northern woods there are years when two or three broods are produced with as many as ten in a brood. Before long the woods are crowded with rabbits. But in the meantime, the lynx, for whom the rabbit is the chief source of food, begins to prosper. More of its offspring find food and survive so that soon larger numbers of lynxes roam the woods. As a result, the rabbits begin to decrease in number. Then the lynxes feel the pinch of hunger. Some may die of starvation and those that survive reproduce less plentifully. Some time after the rabbit population has dropped the lynx population drops, too. This gives rabbits a better opportunity to multiply again. These balances shift regularly, in favor of first one, then the other organism.



Courtesy Am. Mus. Nat. Hist.

Fig. 376. A spider crab with a lower animal form (hydroids) growing on its shell. How might each animal profit by this arrangement?

But the story is not as simple as this. As you read above, there is a tangled web of relationships. At the time that the rabbit population is at its height the rabbits run short of food and are forced to eat the tender bark of young trees. For the period in which rabbits are plentiful the natural increase of the forest is prevented, since the girdling of the young trees kills them. Later, when the rabbit population has decreased, the trees again grow up and reproduce.

There is still another organism that complicates the story. It is thought that when the rabbits are most numerous they are subject to epidemics of disease that travel quickly because the rabbits are so close together. This, too, helps to shift the balance between the rabbit and its environment. As in the case of the lynx, the rate of rabbit reproduction declines when lack of food, disease, and presence of enemies reduce their number. A line drawn to show the rabbit population would go up and down like a wave, showing constant conditions of unbalance, constantly righting themselves.

Ecologists' predictions. Changes in balance take a certain number of years to occur. By careful observation and constant recording of facts biologists are now able to make predictions in the case of a few organisms. They can tell in advance about when each will show an increased or decreased population. But frequently the relations among organisms are so complex that the ways in which balances change have not yet been clearly traced.

Throughout the world changes in balances are continually taking place. But wherever civilized man steps into the picture he tends to disturb the regular changes in balance. *Exercises 5, 6, 7.*

Exercises

1. From what you have observed or from what you have read elsewhere give other examples of food chains.

2. The grass-antelope-lion food chain and the diatom-herring food chain are part of the large carbon cycle of which you have read before. Can you illustrate this in a diagram?

3. *Demonstration.* The frog and the butterfish are the victims of many parasites. Examine liver, lungs, and intestinal canal of frog. Examine teased out muscle of fish.

4. *Demonstration.* Study the green hydra under the microscope. What makes it green? What kind of relationship may this be? Explain.

5. Why is it important for the biologist to know the food habits of every animal? How would it help the farmer to know in which year to expect an increase in rabbit population?

6. The biologist Fabre wrote, "In the great battle of life each organism is first the diner, then the dish." Explain the meaning of the statement.

7. *Summary.* Which of the following six statements do you consider most important in explaining the section you have just read? Which are least important?

1. Symbiosis and parasitism are two types of relationships between organisms.
2. Organisms live in communities. Each organism affects and is affected by some other organism.
3. Since the web of life consists of so many crisscross threads a change in one thread in time affects the whole web.
4. A lichen is made up of an alga and a fungus.
5. A parasite is smaller than its host.
6. When relationships are changed between organisms it is usually only temporary.

Activities for the Junior Biologist

1. You can show relationships within small areas by constructing a terrarium to show forest life on a small scale or one to show seashore life. Be sure to include animal life. Why is a balanced aquarium unsuitable for showing relationships within a small area?

2. Make a careful study of the life in one square foot of pasture land or on one decayed log in the woods. Study the relationships of organisms to one another; study their relative numbers.

3. If you live in an area of woodland or prairie ask adults to tell you about the changes that have taken place in biological relationships in their lifetime. Set aside, for later study, those caused by man. Can you check up on the statements made from memory?

4. College textbooks in ecology will provide numerous examples of interesting plant-animal relationships. Prepare a report on one of these.

5. In a limited way, the hay infusion shows the ways in which a plant and animal population may change. Maintain an infusion, keeping records of the organisms that appear. Take note of increases and decreases in number.

6. Report on Frederick Keeble's *Plant-Animals*, a fascinating account of symbiosis in a worm.

3. Man Tends to Disturb the Balance of Life

Man as a link in food chains. Primitive man was, no doubt, like every other animal, merely one link in several food chains; when he upset the balance in a food chain of which he was a part it soon righted itself because he was no more important in the chain than any other organism. But as man learned the use of tools and learned to dominate the plants and animals in his environment he was no longer one of several equally important links. He became a link that could change the others. When he did so, changes crept in, as you will see. And when they did creep in they did not right themselves. At first, man brought about slight changes in the balance of nature, and since they were within small areas they caused him no great discomfort. Also, changes in balance may be slow in showing their effects. But throughout the years, as civilization has advanced, man has interfered more and more seriously with other living things. He has upset balances; this may have far-reaching and unexpected results.

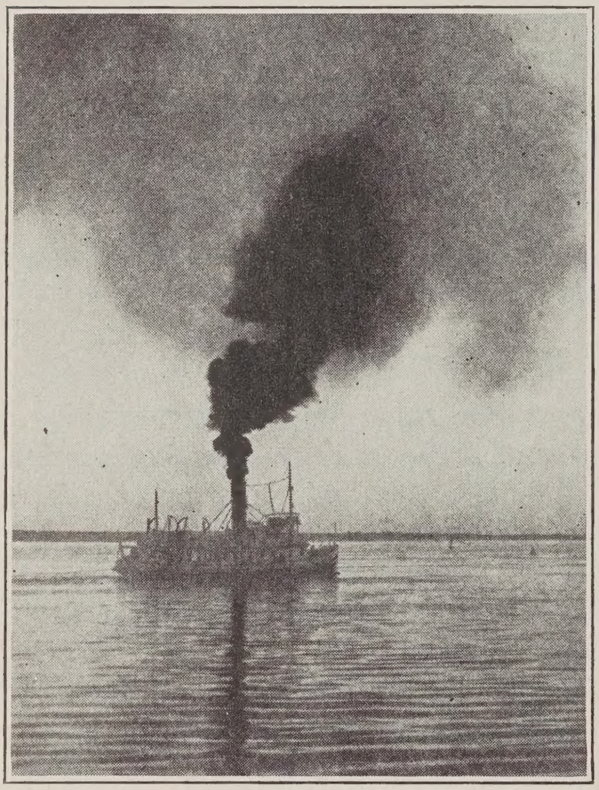


Photo by Alan Sherman

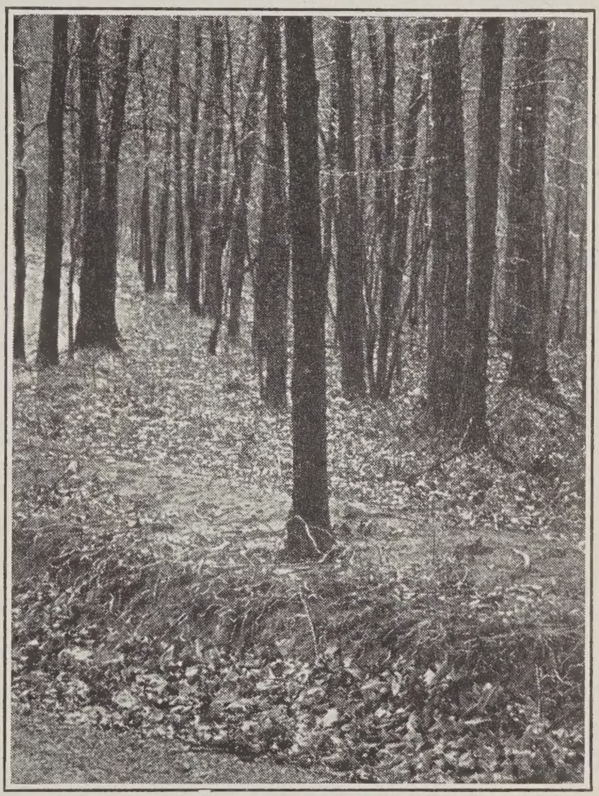
FIG. 377. A single tugboat cutting off the sun's rays. How may river craft and factories affect the health of the inhabitants of a city?

Changes in balance of life caused by the development of industry. The increase in the number of factories and the greater use of machinery have been important factors in changing biological relationships. The development of industries has increased the population of the world. In recent years, it has been growing at the rate of 25,000,000 persons a year. This rapid increase of one link of a food chain would naturally tend to unbalance relationships.

One effect of increase in numbers of human beings has been the growth of cities, which resulted in the destruction of plant and animal life. Where your city or town now stands there once was a forest or a plain; that is gone, and with it the plants and animals which it supported. The waters of harbors and nearby streams are often befouled by sewage and factory wastes. A century ago the Hudson River was well stocked with fish of many kinds; now only a few kinds can survive in it. The Illinois River below Chicago has changed in the same way.

The heavy black smoke belching from factory chimneys, the soot of a million fires, the invisible odorless gas, carbon monoxide, and the other poisonous fumes from automobiles and factories taint the air. In New York City the children get only half as much of the sun's precious ultraviolet rays as they would if they lived a few miles away. It was found in 1930 that the air above every block in New York City contained about two pounds of impurities, invisible to the eye, but damaging to living things of all kinds.

But while cities destroy much plant and animal life they favor the increase of other forms, species undesirable to man, the rats, mice, roaches, and bedbugs. Some of these pests are a more serious problem than they may appear to be. It has been calculated that there may be more rats in a city than there are human inhabitants. The thousands of houses with their loosely constructed walls and many cracks and crannies afford new opportunities for many types of house-dwelling pests. *Exercises 1, 2.*

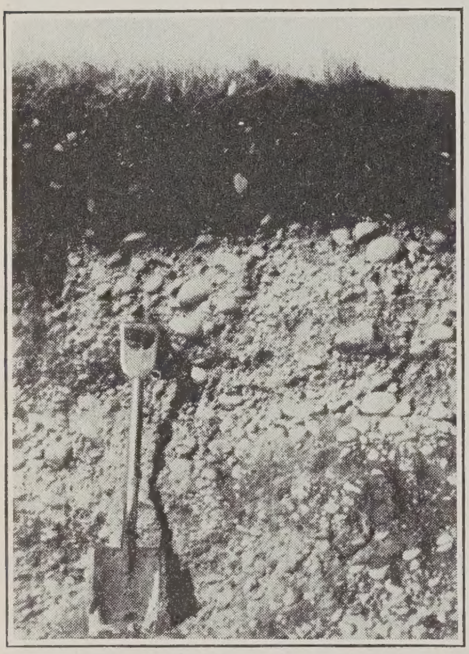


Courtesy Chicago Apparatus Co.

FIG. 378. As the leaves fall and collect and decay, the forest floor becomes spongy. (*Photo by P. E. Okerberg.*)

Destruction of forests has a serious effect on the balance of life. Forests have been cut down for many reasons. They have been removed to make way for the farm, for with the increase in human population it has been necessary to devote more and more land to agriculture. They have been cut for lumber, and, recently, to make pulp for paper.

You could think of many uses of wood. But forests play a far more important part than supplying timber and pulp; they are necessary in preserving the balance among living things. Being large collections of enormous plants they add vast quantities of oxygen to the air. Since they give off much water by transpiration they serve to regulate the humidity of the air and thus make for regular rainfall. Clouds tend to form regularly over large forest areas.



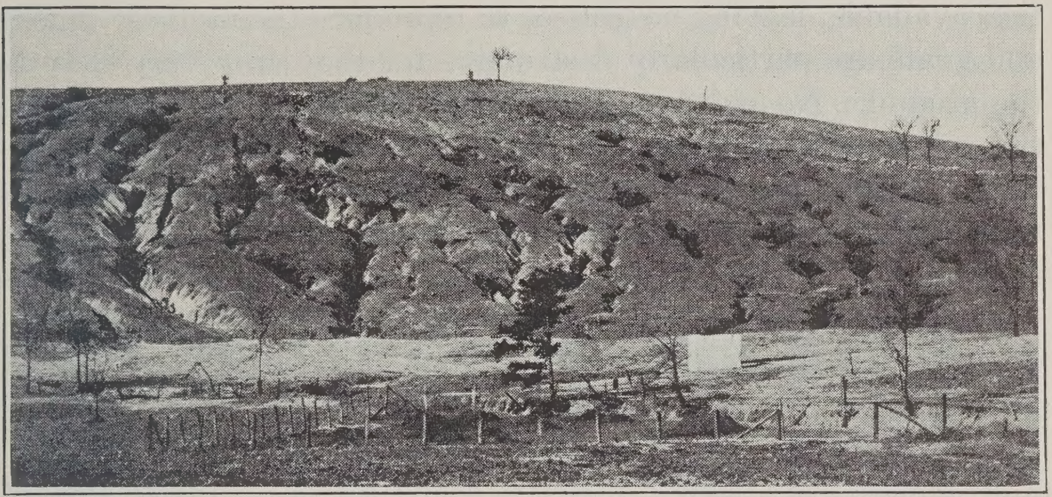
Courtesy Geographic Review

FIG. 379. A hole dug in the earth shows the dark top soil. How thick is it?

But forests do more than this. The masses of dead and decaying leaves and the tangle of roots underground enable the soil to act as a sponge. When large snowdrifts melt and heavy rain storms come the water does not all rush down the forest-covered hillsides. Some of it is absorbed and held by the spongy forest floor. But when forests have been cut and there is no spongy floor the water rushes down into the valleys and the already swollen streams overflow their beds.

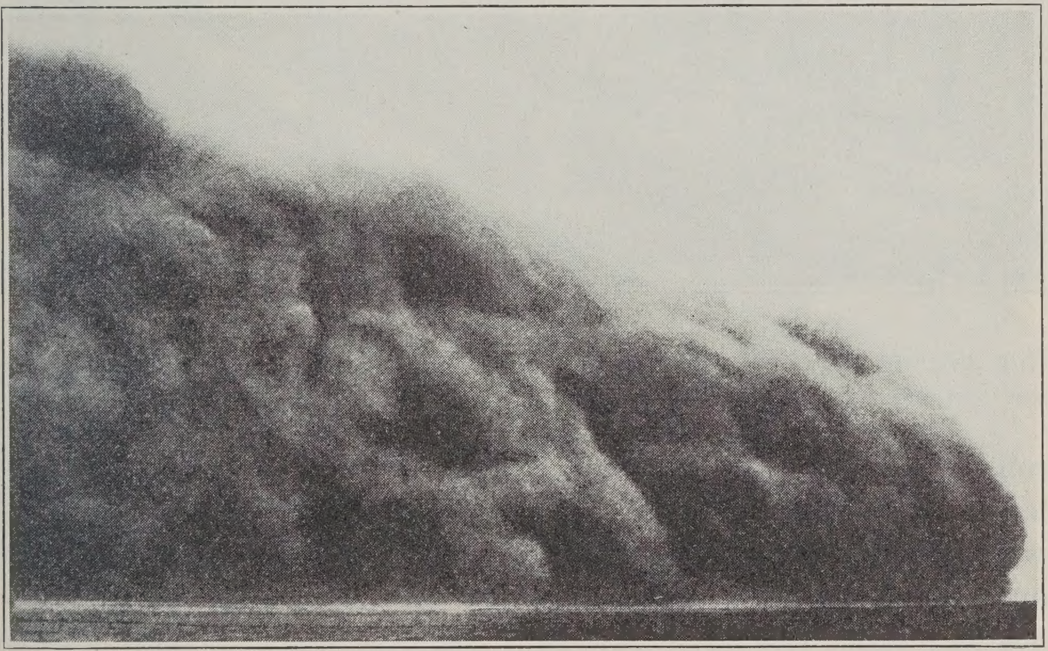
The rapid run-off of water from the bare hillsides has other bad results. Some of the soil washed away by the water is the precious top soil. When the top soil is gone the land is useless for farming and will barely sustain any kind of plant life. Then comes the last chapter of the tragedy. The dry soil in which no plants will grow is whipped up by the wind into dust storms that spoil vast areas of fruitful land by covering the soil. It is man who is responsible for much of this damage to himself.

Forest fires. While lightning seems occasionally to be responsible for forest fires, the large majority are caused by man; the number of fires has increased greatly since "civilized" man has appeared on forest-covered land. Fires have a greater effect on the balance of nature than would be apparent at first glance. Not only is the forest lost but the land, after it has been burned over, is useless for a long time. When forests are destroyed by other causes, for example by a landslide, plants take root rapidly so that one can expect a new growth of trees within fifty or sixty years. But fire destroys much of the organic material (humus) in the soil so that many kinds of plants fail to grow.



Courtesy U. S. Soil Conservation Service

FIG. 380. A hillside that has gone to waste. Can you explain how?



Courtesy U. S. Soil Conservation Service

FIG. 381. Not smoke, but dust whipped up from barren land.

Failure to regulate the grazing of animals produces undesirable effects. When too many animals are put out to graze they tend to destroy pasture land because they are forced to eat all the vegetation available, leaving no grasses to reproduce themselves. Sheep and goats are particularly destructive for they crop very close to the ground. No plants are left to die and decay in the ground; the soil loses the organic material it needs to support vegetation. Besides, the land, stripped of its cover of grass which binds the soil, becomes dry and unfit even for pasture land. It is true that some of the hardier weeds creep in but not enough to hold the soil. Heavy rains carry away still more of the rich top soil. The land becomes poorer and poorer. All this was not known until recent years; for many centuries man has been upsetting plant-animal relationships without paying much attention to his misdeeds.

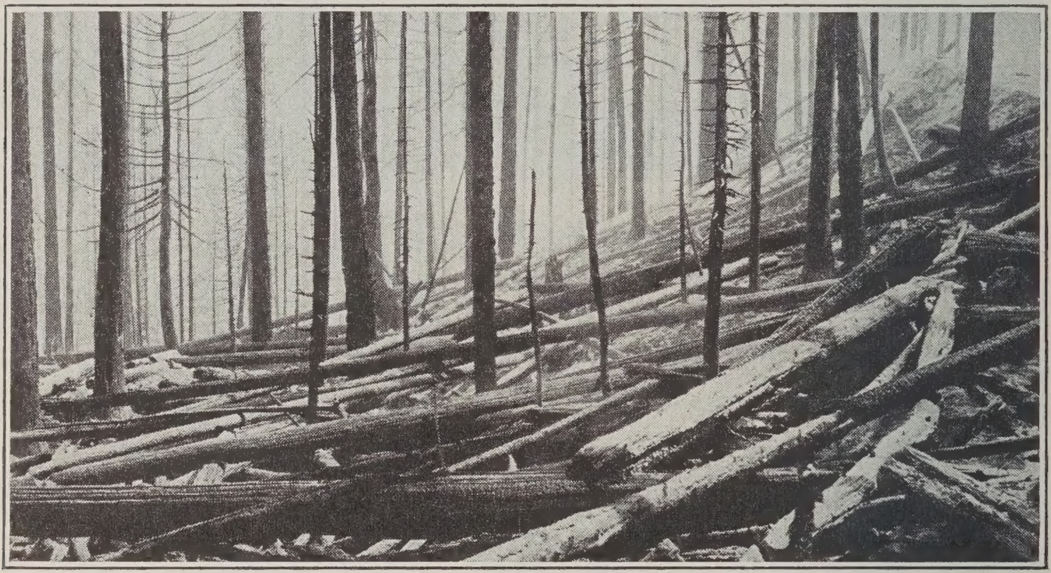


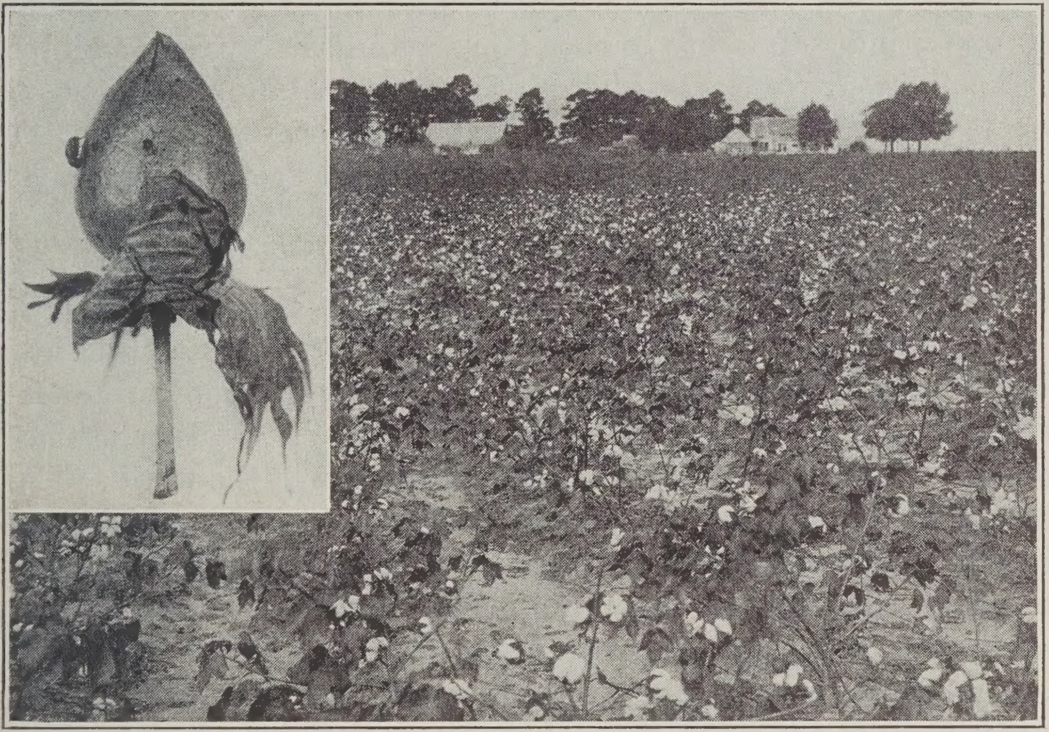
Photo by U. S. Forest Service

Fig. 382. On an average more than twelve million acres of trees in our country are destroyed in this way every year.

The island of St. Helena, the dismal, rocky waste to which Napoleon was exiled, was once luxuriant with tropical plant life. It is reported that in 1513 goats were introduced and there is reason to believe that it was this which reduced the country to its barren state.

It is now known that after cattle and sheep were permitted to enter the Royal Forest in England several hundred years ago they drove out the game and then ruined the timber. When other vegetation is not available cattle gnaw the bark and eat the leaves of the young trees, thus killing them. The Desert of Sahara is moving southward at the rate of one half mile each year. What was once fertile farm and grazing land is being changed to land unfit for human habitation largely because of too much grazing. The bleak moorlands of Scotland, the treeless Mediterranean countries, and the poverty of Spain are all, in part, products of overgrazing. Recently, sections of our own country have begun to show similar effects.

In modern agriculture man establishes a new kind of balance. Nowadays not a few patches but vast fields consisting of many thousands of acres are planted to a single crop. This has enormously increased man's food supply. But at the same time it has increased the food supply of those insects or other animal pests that feed on crop plants. The history of the cotton boll weevil in the South is an illustration. This insect was an unimportant pest in Mexico where cotton plants grew in small patches here and there.



Courtesy A. A. A. and U. S. Bureau of Entomology

FIG. 383. Acre after acre of cotton plants like these have made possible the rapid multiplication of the boll weevil. Inset: A tiny weevil puncturing a boll. It lays its eggs in the boll. The larva destroys the cotton.

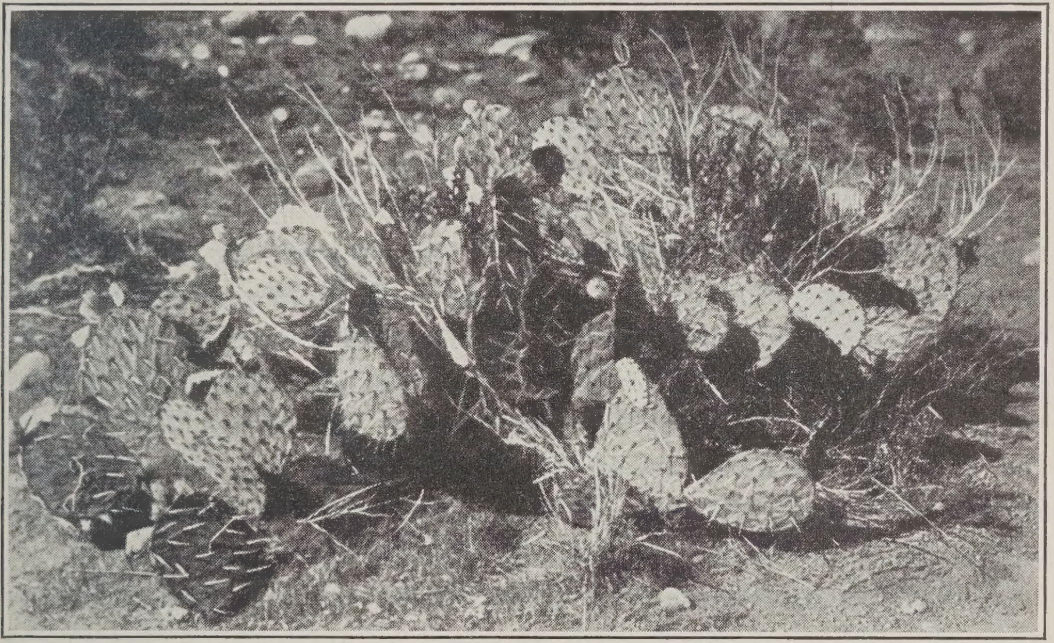
But after the southern planters had given over their land to cotton, planting acre after acre, the cotton boll weevil migrated northward and flourished. In the absence of man, so many cotton plants would have been destroyed that many weevils would have starved; few would have survived to leave offspring. During the next few seasons, therefore, when few weevils were hatched, the cotton plant would have gained a new foothold. In this way, over a period of time, the two organisms would have maintained a changing relationship in which neither destroyed the other but each had its turn at dominance over the other. The balance would have swung back and forth.

But this does not suit man's needs. He wants cotton every year and large amounts of it. He does not wish to wait until insect numbers have become small by starvation and the plant has had an opportunity to multiply once more. And this applies to all his crops and to his flocks and herds of animals. Man puts an end to the changing relationships in which each form has a turn at dominance over the other. He attempts to keep his crops, or flocks, or herds at a permanent steady balance with their insect foes; but he can do this only at enormous cost to himself, as you will read later in this unit.

Changes in balance caused by the introduction of new species. The white man's experiences in Australia have taught an important lesson to the ecologist. When settlers reached Australia they found mammals different from those in the rest of the world. The mammals were marsupials, animals like the kangaroos, which keep their young in pouches after birth. In 1864 an Englishman landed, bringing with him thirteen rabbits from England. These rabbits multiplied; some escaped and spread. Within a few years rabbits overran farms and fields; the continent of Australia was literally suffering from a rabbit plague. Crops were in serious danger. The menace became so great that communities in self-defense were forced to organize rabbit drives in which everyone took part. Thousands of animals were driven into V-shaped traps and destroyed.

But this was not a satisfactory way of handling the rabbit plague for these drives took men away from their work. So foxes, weasels, cats, and skunks were imported to destroy the rabbits. The rabbits decreased in numbers but the introduction of these new animals brought new complications. The balance of life was shifted again, although these later changes were not so serious as the first.

There are many cases of the all too rapid spread of an animal or plant brought into new surroundings. The small water plant, Elodea, was taken some years ago from its native home in Canada to the British Isles. Here it multiplied so rapidly in brooks and canals that at one time it threatened to choke the smaller streams. The muskrat was imported into England by furriers. Though carefully confined, some of the muskrats dug their way out. Now England is spending large sums trying to exterminate the "musquash," as it is called.



Courtesy Nat. Park Service

FIG. 384. The prickly pear, when introduced into Australia, spread so rapidly that soon it was adding a thousand square miles to its range every year.

Our country, too, has not escaped the harmful results of the introduction of foreign plants and animals. During the last century a few innocent little sparrows were brought from England to fight a moth which had been destroying shade trees. Hardy, adaptable, free from timidity, living in quarters which other birds would scorn, eating whatever came to hand, these sparrows quickly multiplied. English sparrows soon established themselves in towns and cities from coast to coast, probably outnumbering any native bird. It was once believed that the English sparrow drove out desirable songbirds. This seems not to be the case; rather, it settles where many other kinds of birds find themselves unable to get along. But it is interesting to note that when it first began to multiply the English sparrow seems to have driven out some insect-eating birds which had been useful in keeping down the tussock moth. Brought over to check one kind of moth which destroyed shade trees, the sparrow soon was indirectly responsible for the increase of a different injurious species of moth. The web of life has many tangled threads. Recently with the introduction of the automobile and the lesser use of the horse, the English sparrow is decreasing in numbers. The starling is another bird introduced from Europe; it, too, has spread with amazing rapidity.

Of course, when the species imported is a wholly useful one, and when it crowds out only useless forms, its spread may be highly profitable. Thus man sometimes unbalances plant and animal relationships to his own advantage. The early settlers of Australia brought not only rabbits but also sheep with them and thus started one of the great industries of the country. Wool is now a source of great revenue and mutton is an important export in Australia. Similarly the potato, which grew wild in the Andes Mountains, was brought to Europe by explorers. It spread rapidly in Ireland and since it multiplied without crowding out any useful crop its importation proved desirable. *Exercises 3, 4.*

Changes in balance caused by accidental importations. Organisms introduced into an area must affect many kinds of plants and animals; discovering the effects is one of the most difficult as well as one of the most interesting problems of the ecologist. But often one effect stands out so clearly from all the rest that it completely holds the attention. This has been the case with some organisms accidentally introduced into this country.

In Medford, Massachusetts, in about 1870, a naturalist was experimenting with various species of silk-producing insects. Among some species that had been sent to him from Europe was the gypsy moth. While he was working with the insects one female moth escaped. The descendants of that moth now rank as one of the worst insect pests attacking shade trees. Since its caterpillar is a hearty eater satisfied with many kinds of food, the gypsy moth has destroyed countless trees. Attempts have been made to correct this change in balance by encouraging other organisms which destroy the gypsy moth. These attempts have been partly successful; that is, the moth has been checked. Man is beginning to establish a new balance between it and its enemies and competitors. *Exercise 5.*

Many plants have been accidentally introduced and have multiplied. In fact, large numbers of our commonest and most troublesome weeds are European importations: chickweed, shepherd's purse, wild carrot, pigweed, and many others. The Ailanthus, the Chinese Tree of Heaven, has crept into backyards in the city of New York and has spread until it now outnumbers any other kind of tree. But plant immigrants of even greater importance than the weeds are fungi of various kinds. A recent immigrant which has caused the country great concern is the fungus which causes Dutch elm disease. The fungus was discovered in Holland in 1919. Where it had come from no one knows. In 1930 it was reported in this country. In 1933, a new and severe outbreak was discovered in New Jersey and New York. Federal investigators have concluded that the fungus entered on logs imported from France. These logs apparently contained both the fungus and two species of bark beetles known to be carriers. The fungus enters the ducts of elm trees and plugs them up. Circulation of water stops, the leaves wilt, and the tree dies. The elm bark beetles now settle in the tree and lay their eggs. When the young beetles gnaw their way out they carry with them the spores of the fungus which has killed the tree. Thus the disease is spread and the fungus, if left unchecked by man, threatens to kill off American elms. By introducing this new pest man upset the balance between elms and their environment. *Exercise 6.*

This fungus is not the only plant immigrant which has injured our plants. White pine blister rust, a type of fungus disease, came to this continent from Europe, probably about thirty-five years ago. By 1915 it was well established in New England. Like the elm, the pine has little protection against this parasite. Once the spores have found a foothold the tree is doomed. But it was discovered that no pine tree could infect another pine. The rust must spend part of its life in a second host, a wild gooseberry or a currant bush. After the parasite has grown to maturity in the berry plant it releases spores which can infect the pine plant.

Among insects there are, of course, many immigrants. The

European cornborer, the Hessian fly, the Japanese beetle, the Mediterranean fruit fly, and the brown-tail moth are other examples of introduced organisms whose effects on plant-animal relationships cost the United States vast sums of money. *Exercise 7.*

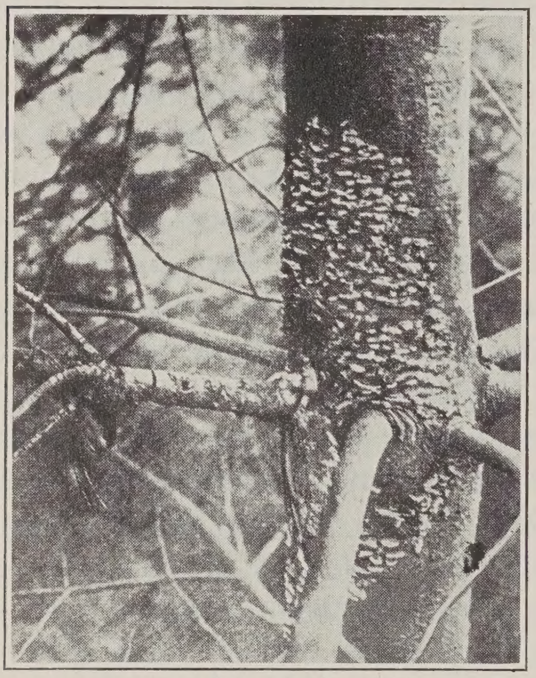


Photo by U. S. Forest Service

FIG. 385. An infected white pine. What could you do if you found a tree like this?

Of interest, too, is the history of the Colorado potato beetle. At one time it fed on a weed in Colorado; but about the middle of the last century it took to eating the leaves of the potato plant which had been recently introduced as a crop plant. Thereafter it gave up feeding on the weed and lived on the potato plant alone. This was a wise exchange, for potatoes were being planted far and wide in the state and the plants grew conveniently close to one another. The beetle rapidly multiplied into hordes. The introduction of a new food supply which happened to suit the insects created as great a change in balance as would the introduction of the insect into a new environment where a huge food supply awaited it.

You can see that man disturbs the interrelations of organisms in many ways. *Exercises 8, 9.*

Exercises

1. Can you name any birds and mammals which have been crowded out of existence by the development of industry? Look up Unit VIII, Part 2, in order to add to your list.

2. Which groups of mammals and of invertebrates seem best able to fit themselves to the new conditions of city life?

3. You are allowed to bring Canary birds into the country. Why are you not allowed to import all other birds?

4. Without careful control of the sheep grazing what might happen to Australia?

5. The common silkworm raised for the silk industry feeds only on the mulberry tree. How would it be an advantage and how a disadvantage if it fed on every type of shade tree?

6. What insects might suffer as a result of the killing off of elms by the Dutch elm disease? Follow up this food chain. With what organism might it end?

7. Report on the harm done by the European cornborer, the Hessian fly, the Japanese beetle, and the Mediterranean fruit fly. Consult the *World Almanac* and books on insects.

8. Look through Part 2, Unit VIII. What insects are mentioned that have upset balances? In each case the balance did not quickly restore itself. Why not?

9. *Summary.* Man disturbs balances by building cities, destroying forests, planting large fields to one crop, raising large numbers of domesticated animals, and by spreading organisms. In each case can you give one or several examples of disturbed balances?

Activities for the Junior Biologist

1. Read Pack and Gill's *Forest Facts.* Tell the class the facts of forest destruction.

2. Prepare a large chart to show the water cycle. Include a forest and a plain.

3. How could you demonstrate that a spongy forest floor prevents water from running off rapidly? Present it to the class. Does it convince your classmates?

4. Have there been forest fires near where you live? Can you find out how they started? Who fought them?

5. Read Paul Sears's *Deserts on the March.* Present a book report to the class.

6. If there are serious plant or animal diseases in your community find out how the local or national governments are fighting them.

7. Make a collection of clippings and pictures from newspapers and magazines bearing on the disturbance of plant-animal relationships. Include those involving man.

4. Man Is Beginning to Understand and Control Plant-Animal Relationships

Man enormously increases the number of his own enemies. You have read that modern agriculture demands that man disturb the normal shifting balance of life. Instead of permitting the boll weevil and the cotton plant to dominate in turn, man persists in raising cotton every year. By supplying food to the weevil continuously, man enormously increases the number of weevils in the world. In one year recently, weevils destroyed $160,000,000 worth of cotton, although huge sums were spent in combating them and countless insects were destroyed. Man has thus created an important enemy.

In the same way man has increased the numbers of many other insect enemies. The cornborer, the Hessian fly, the potato beetle, and many others have grown from insignificance to vast numbers. You can gain some idea of the numbers of insect foes from the fact that in one year the insect population of our country claims $2,000,000,000 worth of crops and agricultural products. By including himself in so many relationships man forces himself to fight continuously against enemies of his own making.

The science of ecology has given man a powerful weapon against animal and plant enemies. The study of ecology has taught man that one cannot disturb plant-animal relationships without serious consequences. But his understanding of ecological facts has also given him weapons against his insect foes. In Unit IX you read of many ways in which man attempts to keep down insect numbers. Much mechanical and scientific skill has gone into the development of poisonous sprays and mechanical devices. But as man came to appreciate how close are the relationships among living things it occurred to him that one might fight organism with organism, plant-destroying pest with parasite or predatory form. *Exercise 1.*

The first use of this type of ecological weapon occurred in 1889 in this country, when the Australian ladybird beetle was imported by government biologists. At that time the fruit growers of California faced severe losses from the scale insect, against which all known weapons seemed to fail; to some, the industry seemed to be doomed. But the ladybird beetle feeds on the scale insect; within a few years after its importation it had won a place as a new link in the insect-tree food chain. After the beetle destroyed large numbers of scale insects the three organisms then settled down to a balance in which the scale insect plays too small a part to destroy all fruit trees, although it still injures many.

In Hawaii a leaf hopper threatened to destroy the sugar cane industry. Biologists were employed to hunt for an ally, an organism to reduce the numbers of the insect enemy. In the course of their search they found several, among them a wasp from Australia and a bug from Fiji. Within a few years after the importation of some of these insects all danger of destruction of the crop had been removed, although the hopper was not exterminated. It still takes a heavy toll. *Exercise 2.*

Man unbalances relationships needlessly. While some unbalanced relationships are necessary for man's well-being others are unnecessary and the result of his thoughtlessness. You have read of the harmful results which may follow the careless cutting of forest trees. In our country this unbalancing of relationship has become serious because man has been shortsighted, wasteful, and ruthless in his work. Until recently forests were destroyed without thought of consequences. Even now, every year, 160,000,000 trees of average size are cut in the United States, as many as would cover all of Massachusetts, Connecticut, and New Jersey.

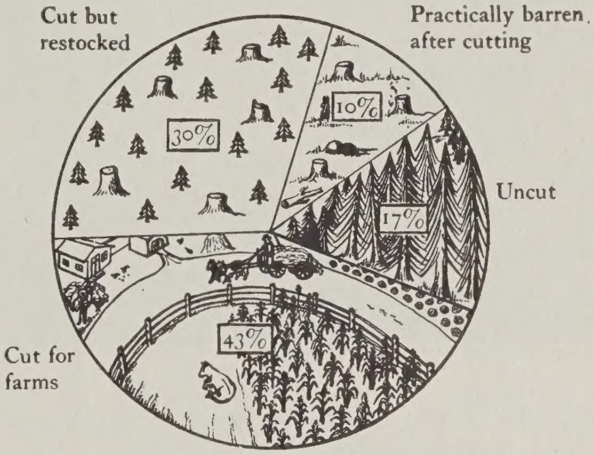


FIG. 386. When the first settlers came to this continent, there were more than 800,000,000 acres of untouched forest. How much is left? What is being done to improve this situation?

Man has disturbed plant-animal relationships in other ways, when draining swamps, building dams, constructing highways, and settling in large cities. By exercising care and employing the science at his command he can largely avoid unbalanced relations of this kind. Within recent years he has begun to realize this fact and to take steps both to conserve (save) and to restore more desirable plant-animal relationships.

The forest conservation program. About fifty years ago, in 1876, the United States Forest Service was established as part of the Department of Agriculture. In time, schools of forestry were established in many parts of the country; new professions, such as those of forester and forest ranger, arose in connection with this work. These men have learned important facts about forests.

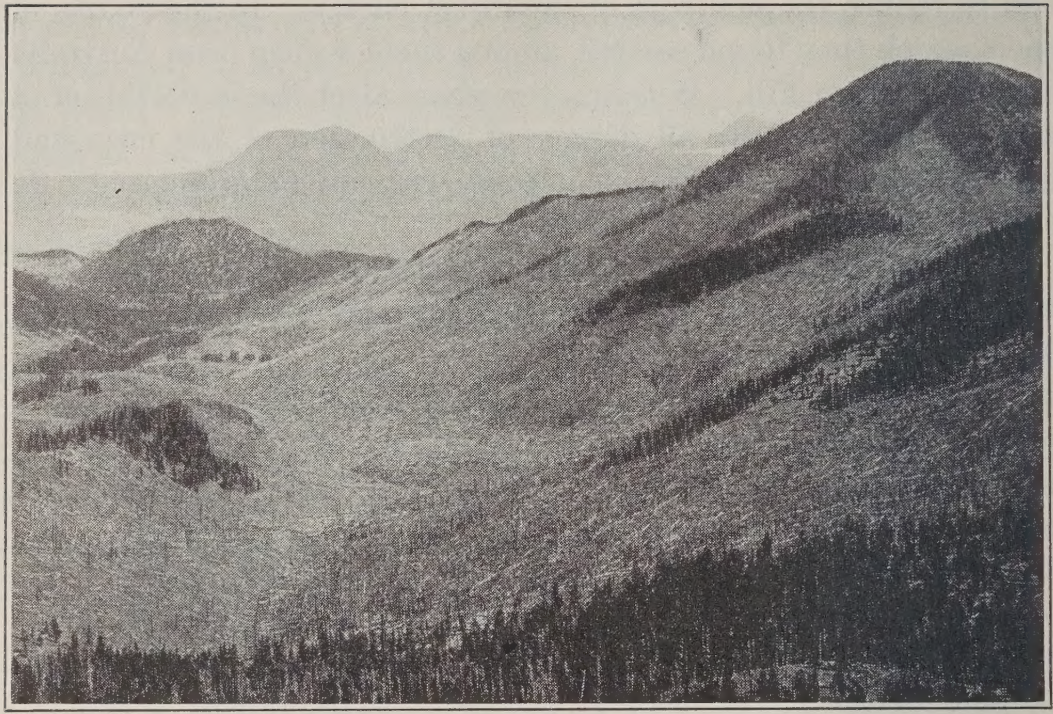


Photo by U. S. Forest Service

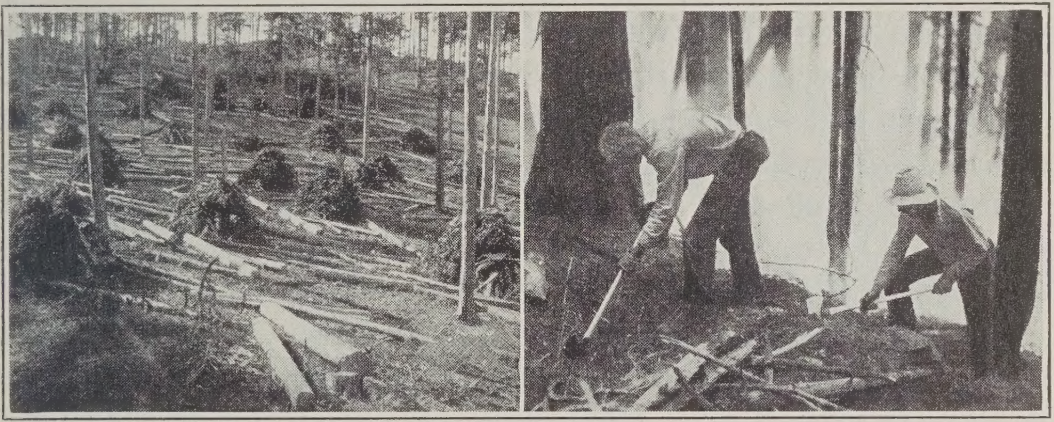
Fig. 387. What fire can do to a watershed. What will be the result when rain falls here?

Photo by U. S. Forest Service

Fig. 388. The forest officer watches for the ever menacing forest fire.

It takes a forest tree between fifty and one hundred years to grow to such size as makes it suitable for cutting. The first rule of conservation, to use only as much as will be naturally replaced, may be applied arithmetically: the man who owns 50,000 trees ready for cutting should cut less than 1000 every year. The trees to be cut should be carefully selected. If it is properly spaced, cutting in a forest is desirable, for it gives small trees just enough freedom and light for tall straight growth.

Planting is rarely necessary in a well established forest, for young trees appear regularly from the seeds which drop. But there is much land now used for crops or pasture that is fit for nothing else but forest growth. In such places prompt reforestation (planting of trees) is recommended by the government. *Exercise 3.*



U. S. Forest Service *Photo by U. S Forest Service*

Fig. 389. Clean lumbering (left) reduces the fire hazard. (*Photo by Paul D. Kelleter.*) Digging trenches (right) to keep forest fire from spreading.

The vanishing of wild life. With the destruction of the forest and the settling of the plains much wild life was destroyed. In some cases this had serious results; in others man has not been seriously affected. Elk must once have roamed our eastern woods. Bison were described by the first white men who landed in Maryland. They were at home in the region where the White House stands today. The California grizzly is extinct. The wild turkey, which once inhabited nearly every state, is no longer common. In 1844 the last great auk died. The year 1914 saw the end of the passenger pigeon, which at one time could be bought in the market for a penny a bird; and as recently as 1932 the heath hen became extinct. One could make a long list of species whose numbers have decreased alarmingly. Wherever man enters with his gun he disturbs plant-animal relationships. This is often caused by greed or ignorance.

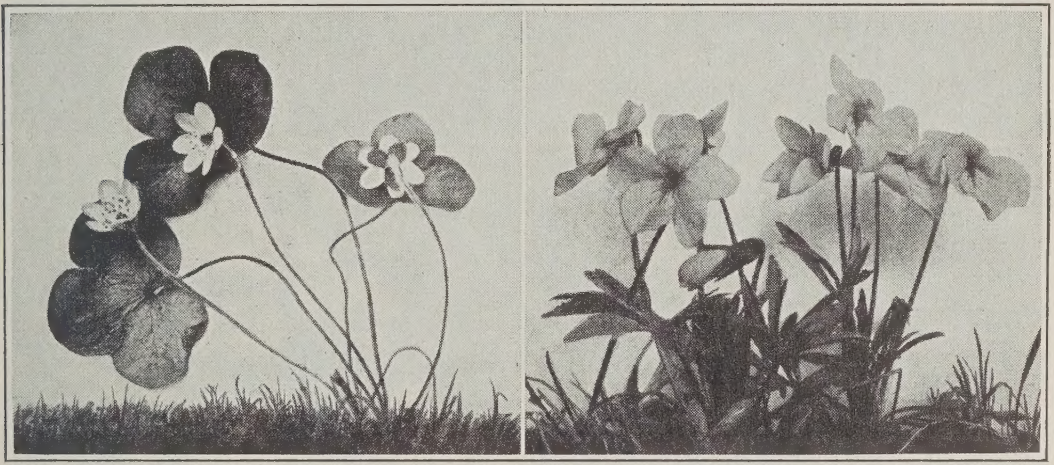
Steps taken to conserve wild life. Ecologists have for some time realized the danger of upsetting natural balances. The Federal Government created the Bureau of Biological Survey to study plant-animal relationships and to help restore more normal and more advantageous balances. In many parts of the country colleges are now giving courses in wild-life conservation. Before man can attempt to save wild life and restore species to their natural places he must experiment and observe. He must understand what physical conditions suit the animal best, what its natural food is, what else it will eat, what enemies prey on it, what diseases attack it, how rapidly it reproduces, and a host of other facts. Many men and women are now taking up wild-life conservation as a career. *Exercise 4.*

The government is attempting, too, to teach farmers how to raise some of the smaller mammals and the birds useful as insect destroyers. The idea of raising wild life as one would raise crops of plants is gaining favor throughout the country. Of course, if this is done without expert knowledge of biological relationships it is a dangerous procedure. Attempting to restore former balances without a knowledge of the necessary facts might well result in new and undesirable shifts in the balance of life.

And what is true of the United States is true of other countries, too. The Soviet Union realized that the beaver, so valuable to Russia for its fur, was as near extinction as was the bison in our country some years ago. Steps have been taken to restore it and to protect its breeding grounds. Ecologists the world over are stressing the importance of understanding plant-animal relationships in order that many industries may be saved.

But it is not only our government which is trying to conserve wild animal life. There are many associations, such as the National Association of Audubon Societies, that do the same sort of work. Some of them seek to obtain laws for the conservation of wild life, attempt to educate the people, and buy large tracts of land where each of our threatened species, such as mountain goats, mountain sheep, antelopes, wild geese and ducks may live and breed without interference from man. Such places are called *sanctuaries* (places of refuge and protection). There are many scattered throughout the country. No one may hunt or in any way injure wild life on a refuge or sanctuary. *Exercises 5, 6.*

Bird and game laws. In an effort to protect birds against the thoughtless activities of hunters, state and federal laws have been passed. One law (the Lacey Law) prohibits shipping birds out of the state in which they have been illegally killed. In the days when the snowy egret was being killed wholesale in the Florida swamps to provide feathers for women's hats throughout the country this law was necessary. Another law (the McLean Bill) makes it unlawful to kill insect-eating birds of any kind. There is a Migratory Bird Treaty between the United States and Canada which protects those birds which travel between the two countries. Without a treaty it would be useless to protect such birds in the United States. To provide money for refuges for migrating birds two Migratory Bird Conservation Bills have been passed by the Congress of the United States.



Courtesy U. S. Dept. Agri. *Am. Mus. Nat. Hist.*

FIG. 390. Wild flowers that need protection. Hepatica on the left. Bird's-foot violet on the right. Picking or uprooting them is forbidden in several states. (*Photo by Mary C. Dickerson.*)

Other forms of animal life are also protected by law. Some are completely protected; some may be hunted during a short "open" season only, never while the young are dependent on their parents. In the case of some game the season is made extremely short and the number of animals that may be killed by one person is limited. The young may not be caught or killed. In short, the killing is

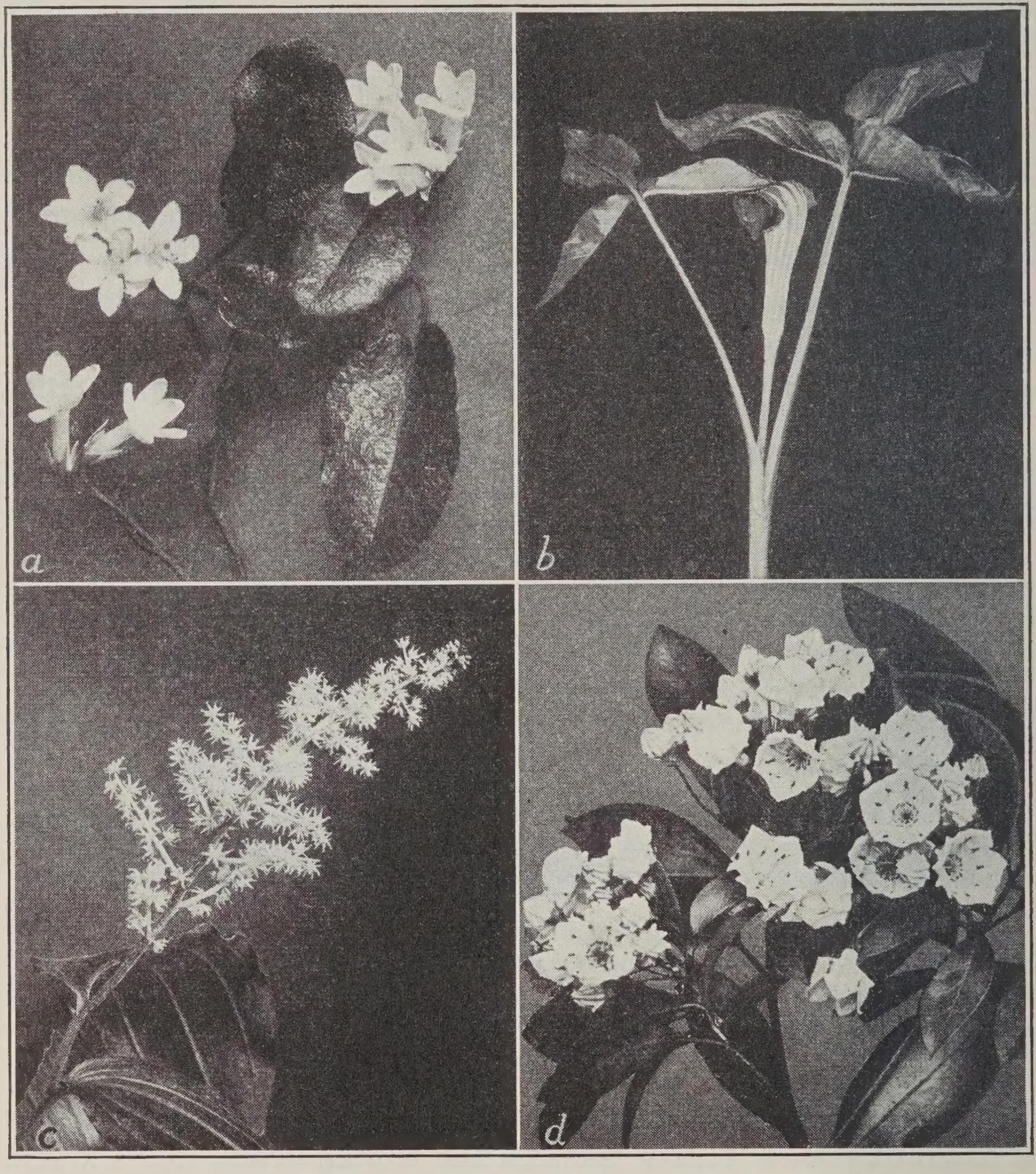


FIG. 391. Many of the flowers that bloom in the spring need protection. Can you think of a reason for this?

a. Trailing arbutus. (*Courtesy Am. Mus. Nat. Hist.*)
b. Jack-in-the-pulpit. (*Courtesy Brooklyn Botanic Garden.*)
c. False Solomon's seal. (*Photo by Mary C. Dickerson, Courtesy Am. Mus. Nat. Hist.*)
d. Mountain laurel. (*Courtesy U. S. Dept. Agriculture.*)

so carefully controlled that, if the laws are enforced, destruction of the species is impossible. Of course, fish are protected in this way, too. On your town post-office bulletin board you are likely to find government notices stating these facts. *Exercises 7, 8, 9, 10, 11.*

Besides laws to protect wild life, education in conservation is necessary. Man must learn to understand and how to control plant-animal relationships.

Exercises

1. Look back to Unit IX. List, with examples, all the devices mentioned for the destruction of insect pests.

2. Make plans for a "Hall of Fame" for those mammals, birds, insects, or other animals in your vicinity which deserve to be so honored. How will you decide which are to be chosen? If possible, arrange a large cabinet as a Hall of Fame, using pictures where actual specimens are not available.

3. Suppose that you were the director of a lumber company that owned vast stretches of forest land. What regulations would you issue to prevent forest fires on your land? What fire-fighting training would you give your employees?

4. By discussion with the class plan a thorough biological survey of a small field or city lot near your school. If the season permits, carry it out. Prepare a scientific report of the work.

5. Divide the class up into committees and obtain information about organizations that help to maintain normal plant-animal relationships. Include the Bureau of Biological Survey, the United States Forest Service, your State Department of Conservation, Fish Hatcheries, the American Tree Association (Washington), and others.

6. Ask the National Association of Audubon Societies how your class can take out a Junior membership.

7. Factories and large cities interfere with normal plant-animal relationships with the environment. List some of the ways in which such interference may take place. How may man protect the living things that are harmed by cities and factories? How may he protect himself?

8. To find an organism to help you fight some insect foe would you look in a region where the insect foe does not live, where it lives in small numbers, or where it is very common? Give a reason for your answer.

9. Report on any movie you have seen or any broadcast you have heard on the subject of wild-life extermination or conservation.

10. *Summary.* The first two paragraphs give you two interesting biological ideas. Can you explain and illustrate them? Then you are given practical facts about how man can more wisely control relationships. State these briefly in outline form.

11. *Unit Summary.* There are several important ideas in this unit. You can summarize it by answering these questions:

(*a*) How are materials used again and again on this earth?
(*b*) What is a food chain?
(*c*) In what ways do organisms affect one another?
(*d*) How do balances shift?
(*e*) How does man affect other organisms?
(*f*) Why does man affect other organisms so much?
(*g*) What practical methods does man have for regulating the relationships of other organisms?
(*h*) What is meant by the balance of life?

Activities for the Junior Biologist

1. If you are interested in the work of the forester or forest ranger find out where you could prepare yourself for this profession, what the requirements are, and so on. Report to the class.

2. Can you visit a bird refuge? Do you know whether there are any in your state? Report.

3. Read and report on Hornaday's *Wild Life Conservation in Theory and Practice* or Pack's *Forest Facts for Schools.*

4. Charts of plants and animals that need protection would be of great help to your school.

5. If you can reach a large natural history museum study some ecological exhibit carefully and take full notes on every interesting observation you make. Discuss these with someone else who has studied the same exhibit or present your report to the class.

6. D. C. Peattie has written a most interesting life of Audubon. Read it.

7. Your State Agricultural Station may be able to supply information about reforestation. If you live where such work is possible some of your classmates and you might undertake a tree-planting project.

8. Tell the story of Johnny Appleseed's life to your classmates. (Consult an encyclopedia.)

Good Books to Read

Borradaile, L. A., *The Animal and Its Environment.* Frowde, Howder, and Stoughton.
Boulenger, E. G., *A Natural History of the Seas.* Appleton-Century.
Bower, F. O., *Plants and Man.* Macmillan.
Brindley, H. H., *Forest, Steppe, and Tundra; Studies in Animal Environment.* Macmillan.
Campbell, D. H., *Outlines of Plant Geography.* Macmillan.
Chase, S., *Rich Land, Poor Land.* Whittlesey House.
Doane, R. W., *Common Pests.* Thomas.

Elton, Charles, *Animal Ecology.* Macmillan.
Gustafson, A. F., *Conservation of the Soil.* McGraw-Hill.
Henrici, A. T., *Bacteriology.* Heath.
Howard, L. O., *The Insect Menace.* Appleton-Century.
McDougall, W. B., *Plant Ecology.* Lea.
Needham, J. G. and Lloyd, J. T., *The Life of Inland Waters.* Thomas.
Pack, C. L., *The School Book of Forestry.* Lippincott.
Peattie, D. C., *Cargoes and Harvests.* Appleton-Century.
Pinchot, G., *The Training of a Forester.* Lippincott.
Robbins, W. W. and Ramaley, F., *Plants Useful to Man.* Blakiston.
Sears, P. B., *Deserts on the March. This Is Our World.* Univ. of Oklahoma.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.

UNIT XII. CONSTANT CHANGE IS CHARACTERISTIC OF THE EARTH AND ITS INHABITANTS

1. Changes Are Constantly Taking Place in the Surface of the Earth
2. The Study of the Rocks Enables Man to Reconstruct the History of the Earth and Its Inhabitants
3. At Various Stages in Its History the Earth Presented Very Different Scenes

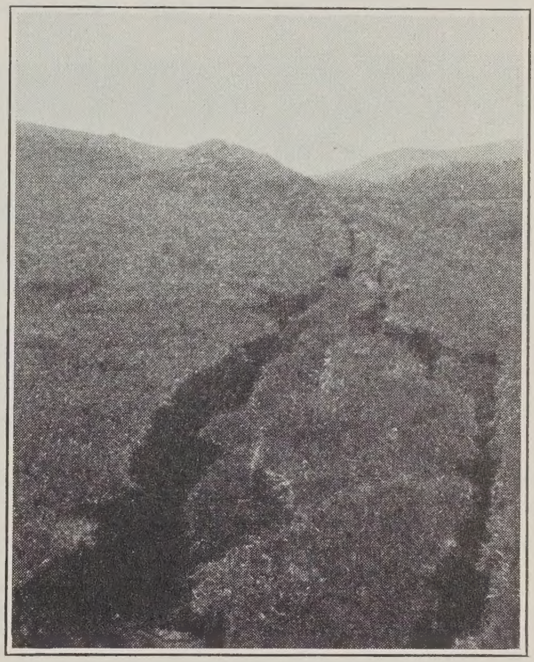
1. Changes Are Constantly Taking Place in the Surface of the Earth

Detecting changes in the surface of the earth. There are changes in the surface of the earth that are easily noticed; they go on under your very eyes. Indeed, all of you have seen such changes occurring. It may have been the washing away of a bare slope of ground after a heavy rain or the cutting of a new channel as a great river in flood tore its way through fields. You have read of even more dramatic changes, the crashing rush of an avalanche which brought rock and soil down a mountainside or the changes which accompany an earthquake or volcanic eruption.

There are other changes which are not so easy to note because they occur less swiftly. These are the more common, in fact. To detect such changes man must keep records which can be compared from time to time. In northern Sweden men have for centuries made marks along the shore to show how far up the sea reached. In this way they discovered that the land was slowly rising at the rate of about two feet each century. Nowadays, scientists keep careful records. Without these, man would often fail to detect slow changes and would frequently be misled by personal impressions. *Exercises 1, 2.*

Striking changes in the surface of the earth. In 1887 northern Mexico was visited by a tremendous earthquake. In this case the earthquake appeared in a mountainous region; in some places the mountain range was raised as much as twenty feet in a few moments. Frequently there are earthquakes that are not accompanied by any visible change in the surface of the earth like those described above. But the shaking and quivering are always a symptom of tremendous changes going on below.

Equally striking are the rapid changes which result from the eruption of a volcano. Some volcanoes are slow, others explosive in their action. The explosive peaks like Mont Pelée and Krakatoa have been known to hurl forth enormous amounts of molten (melted) rock and ash. The greatest explosion of which there is record occurred in 1883 when Krakatoa blew away a cubic mile of rock in dust and ashes. It may help you to get some idea of the vast amount of rock displaced to know that according to the statement of reliable scientists the cloud of ashes rose seventeen miles into the air, completely hiding the sun. *Exercise 3.*



U. S. Geological Survey

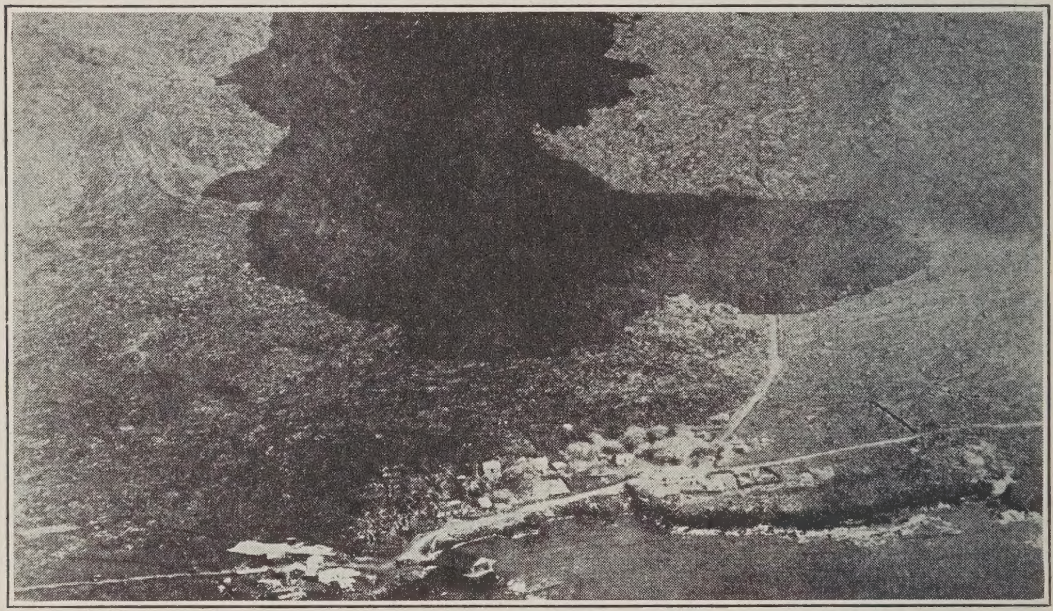
Fig. 392. A crack which appeared during the San Francisco earthquake of 1906. This crack extended for 600 miles. (*Photo by G. K. Gilbert.*)

Other less explosive volcanoes pour out masses of molten rock known as *lava* (lah′va) more slowly. What is now the island of Hawaii was once little more than some volcanic peaks rising out of the ocean. With every eruption large masses of lava flowed out of the craters and down the sides. These cooled and built up the shores of the island.

Of course, great volcanic eruptions and earthquakes are comparatively rare. For this reason, the changes caused by them are far less important than the slow changes that occur steadily all over the surface of the earth.

Gradual changes made over long periods of time. Continents seem to be such solid masses of rock and soil that it is not easy to believe that they change. Yet there is clear-cut evidence that within historical times continents have altered both their shapes and their sizes by rising and falling. Of course, the change is so slow that no man can see a continent rise or fall.

Perhaps the most interesting evidence of the rise and fall of land is found near Naples, Italy. Some columns of marble remain standing near the seashore, all that is left of a temple built by the Romans. As high as twenty feet above the ground the columns show holes bored by a snail-like animal that lives in the ocean; in fact, the shells of some of these animals are still to be found in the holes. Evidently, these columns were once under water. Scientists have concluded that since the time when the Romans built the temple, about 1900 years ago, the land on which the temple stands must have sunk beneath the ocean to a depth of twenty feet, remained there at least long enough for the molluscs to dig tunnels in the marble, and then risen again.

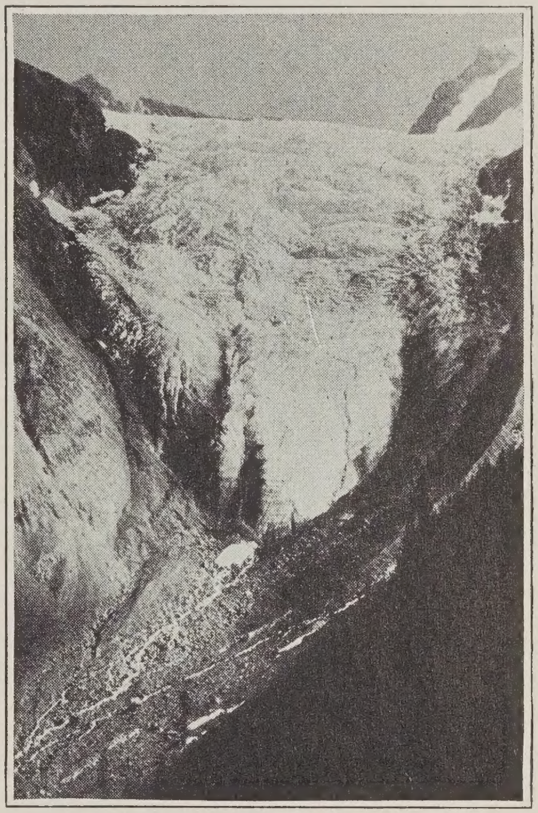


Courtesy Aeronautical Chamber of Commerce

FIG. 393. Lava from one of the Hawaiian peaks approaching a fishing village. These lava flows have been known to extend 50 miles.

Streams build up and tear down land. But there are some gradual changes that go on faster. Some of them can be noted within a lifetime. The laying down and piling up of soil material by a river is one such change. Where a river flows into a large body of water, such as the ocean, its current suddenly slows up and much of the load of mud which has been carried along by the moving stream settles to the bottom and piles up. As the years go on this deposit rises above sea level to form mud flats, through which run the channels by which the river empties into the ocean. In time seeds fall on the mud flats, plants grow, and the new land becomes so firm that men may live there. The whole formation is called the *delta* of the river. So much land was laid down at the mouth of the Mississippi between 1852 and 1905 that any person living there during that time could have noticed the change.

Every river in the world builds land in the same way. The delta of the Ganges has an area of more than 40,000 square miles; the delta of the Nile has for centuries been the home of millions of persons. Of course, far more material is carried down by a river than appears in its delta. Much of it is carried out into the ocean. It has been calculated that the Mississippi carries each year a total load of 517,000,000 tons of solid material, dissolved, suspended, and rolled along its river bottom. *Exercise 4.*

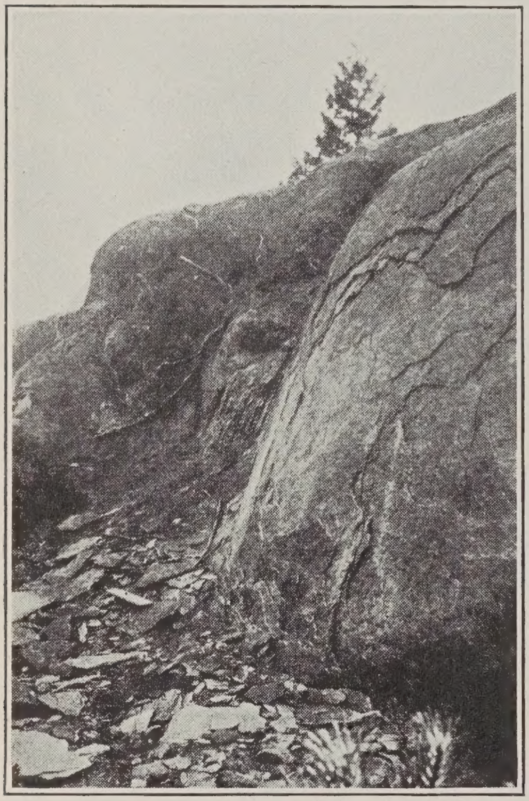


Courtesy Geol. Survey of Canada

FIG. 394. Rivers of ice, known as glaciers, wear away the land. Can you see the broken rock below the glacier?

Such constant building up of the surface of the earth must mean the corresponding tearing down of some other part of the land. The sand, clay, and pebbles that the rivers of the world carry are not present in water when it falls as rain. These materials come from the wearing away of the earth, chiefly by the small brooks that feed the river. Some of the soil material is washed into the brooks and rivers by the rain as it runs down the hillsides. You can see this washing-away process going on during every heavy rain on bare slopes which have no decaying matter, roots, or dead leaves to hold the soil.

When the slope is steep the rushing waters may form a brook which carries not only clay particles and sand but pebbles and larger stones. These cut away the soil along the bed of the brook and by their rubbing and pounding wear away the very rock itself. Streams, therefore, wear away or *erode* (ee-road′) soil and rock, which are then carried off to the ocean. It is some of this eroded material which may later be built up into a delta.



U. S. Geological Survey

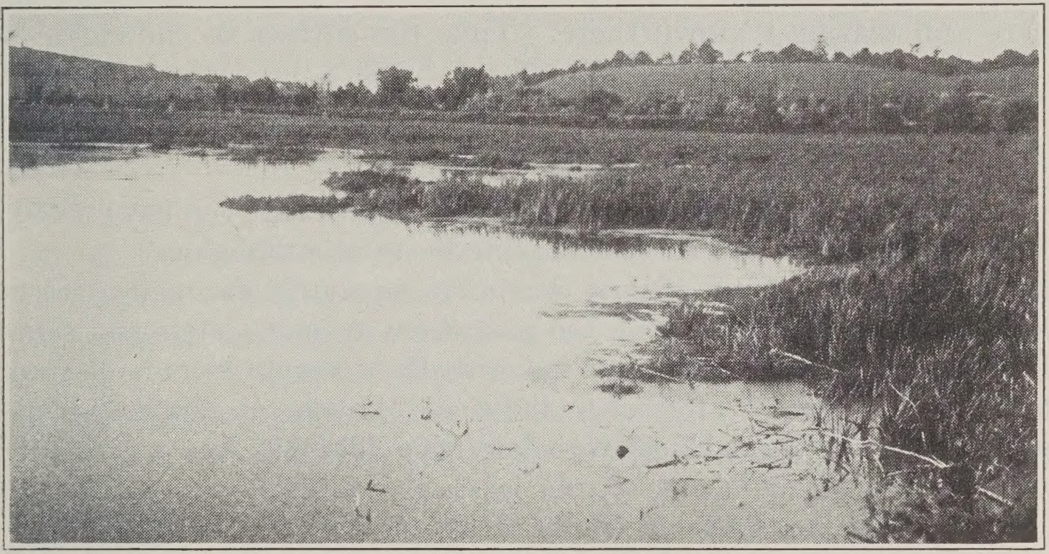
FIG. 395. As the temperature changes the expansion and contraction of the surface layer causes the rock to scale. (*Photo by G. K. Gilbert.*)

Other ways of tearing down land. Even where there are no streams to cause erosion there are many forces at work which tear down rock and soil. Changes in temperature cause rocks to crack. The freezing of water in these cracks breaks the rock up into smaller pieces. This breaking up and crumbling of rock in the air is called *weathering*. Rocks may also be acted on chemically. Some, like limestone, dissolve readily in soil water which is slightly acid. Many underground caves have been formed in this way. *Exercise 5.*

Erosion and weathering go on steadily everywhere in the world. Their effect is to break rock into smaller and smaller pieces and thus finally into soil. Erosion and weathering are most rapid on mountains, from which the soil is steadily swept downstream. Mountains thus tend to flatten out gradually; the lowlands tend to be built up by the soil that is deposited on them. This building up does not go on as fast as the breaking down because much of the soil is carried into the oceans. It has been calculated that the height of the United States is reduced one foot every seven thousand to nine thousand years.

Land built by plants and animals. Plants may settle on the mud flats of a delta. Their roots bind the soil together and make it firm. After the plants die their decaying bodies make the soil richer. When the mud flats are high enough they become dry and other types of plants settle there. Finally trees and shrubs appear, for their seeds now find conditions suitable for growth.

Much the same thing happens wherever there is a small lake. Plants dying at the edges and mud brought down by streams collect along the shore and build up swampy lands. The lake grows smaller as its shores march out into it. Swamps are soon replaced by meadows and meadows by forests. In time, where once there was a lake, a forest stands, often with a small brook trickling through to drain the land.



Courtesy New York State College of Agriculture

FIG. 396. As the plants advance into the lake, it becomes swampy. How does the swamp, in time, turn into a meadow?

Some animals, too, play their part in building up land. As you have read, corals grow in great masses in tropical waters. Their skeletons form limestone rock which may rise above the surface of the sea as a reef or island. Sand and soil are washed up on the rock; the seeds of land plants carried by wind or water settle on the land and germinate. The Bermuda Islands came into existence in this manner.

How living things affect erosion. Plants are of importance in hindering erosion since their roots bind the particles of soil together. Decaying plant material, too, acts as a strainer, holding back the soil but letting the water go through slowly. On the other hand plants help to break up rock; sometimes a seed falls into a crack by accident and the growing plant eventually splits the rock; more regularly plants destroy rock by secreting acids into the soil through their root hairs. These acids dissolve away parts of the rock.

Animals affect erosion to a much slighter extent but the habits of the ground burrowers make for a general loosening of the soil which helps erosion and weathering. *Exercise 6.*

Living things, including man, join with the other forces acting on the surface of the earth to refashion the land, building it up here and tearing it down there. Thus the surface of the earth is constantly changing. *Exercises 7, 8.*

Exercises

1. Recall to mind changes in the earth's surface that you have noted. Prepare a report for the class, describing the most striking one.

2. Consult five or ten of your classmates separately about their recollections of the weather during the past three or four winters and summers. Then compare these reports with the accurate records of your local weather bureau. Report to the class. If you can obtain the impressions of adults for longer periods of time, do so. Why are records valuable?

3. Read the newspaper carefully each day for notices of earthquakes or other earth changes. Clip such articles and paste them in a scrapbook.

4. (*a*) *Demonstration by teacher or pupil.* Prepare two mounds of earth, each in a box. Cover one mound with sod. Leave the other unsodded. If possible, use soil containing clay for the unsodded mound. Using a watering can, pour the same amount of water on each mound. What do you demonstrate by this means?

(*b*) When doing the demonstration above, collect, in separate containers, the water which has run off each mound. Pour each through a separate funnel, lined with filter paper. Does the kind of country drained by a river make a difference in the speed with which a delta forms? Explain.

5. *Demonstration.* The slow action of carbonic acid on limestone can be shown, speeded up enormously, by using a stronger acid. Pour hydrochloric acid on marble chips. What becomes of the marble?

6. You can show the force of germinating seeds by planting some soaked pea and corn seeds in moist sawdust or sand in a tumbler. Cover the surface of the sawdust or sand with paraffin, making holes in several places (where no seed has been planted) so as to allow the air to reach the germinating seeds. Can you devise any other experiments to show the force of germinating plants?

7. *A class exercise.* Prepare a bulletin board demonstration of pictures showing the changes man has wrought in some parts of the earth:

(*a*) In construction of reservoirs or dams to impound water.
(*b*) In the changing of shore lines near cities.
(*c*) In the irrigation of deserts.
(*d*) In the reclamation of swamp land by new drainage.

8. *Summary.* Some of the changes taking place in the earth's surface go on all the time. List these. Others occur from time to time. Make a list of them. Which seem to be more effective? To check your understanding of this work, prepare two other lists, one containing the changes that build up the earth's surface; the other, the changes that tear it down.

Activities for the Junior Biologist

1. Report to the class on the work of the U. S. Geological Survey at Washington. What agencies that keep records can you find out about?

2. Look through back numbers of the *National Geographic Magazine* and report to the class on earthquakes or volcanoes. Try to explain to your classmates what happened inside the earth.

3. Using two flat rocks and some packed, wetted soil, demonstrate how the slipping of the underlying rock causes rifts in the soil or displacements.

4. Prepare a clay model of a volcano. Use agar or gelatin to simulate lava. Then demonstrate how the lava forms new rock after it has flowed down the sides of the volcano and hardened.

5. Prepare a model of a river delta, showing how it grows.

6. Prepare a short report on the "bad lands" of the West. Explain how they were formed and why the soil is not yet completely washed away. Consult a geology or physiography textbook.

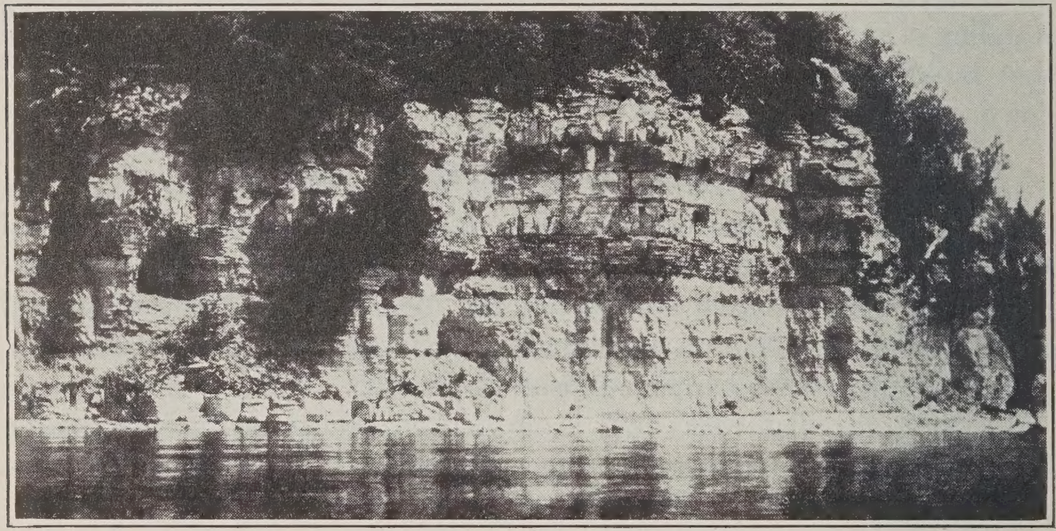
7. If you are interested in photography, take pictures of lakes which seem to be in different stages of change. Arrange them in a series and mount them to demonstrate how a lake disappears.

8. Prepare a report for the class on the activities of such ground burrowers as moles, woodchucks (groundhogs), or field mice.

9. The camera is the best recorder of all types of earth changes. Why not prepare a list of subjects such as a bare slope before and after a heavy rain? An album of such shots can be prepared anywhere.

2. The Study of the Rocks Enables Man to Reconstruct the History of the Earth and Its Inhabitants

How rock is formed. You have just learned how rock is broken up by erosion and weathering, the large pieces becoming smaller ones. You learned how the water of streams and the ocean waves wear away the land; how rushing water carries the particles of sand and silt (fine earth) along until it flows more slowly at the mouth of the stream or in some wide bay. Here the solid particles settle down. They form a *sediment.* If the land sinks, this sediment will be buried deep beneath the sea and its particles pressed together by the great weight of the water above. Even without this enormous pressure the sediment slowly hardens, for substances dissolved in the water act as a cement that binds the particles together. Thus, rock is formed out of the sediment. It is known as *sedimentary* rock.



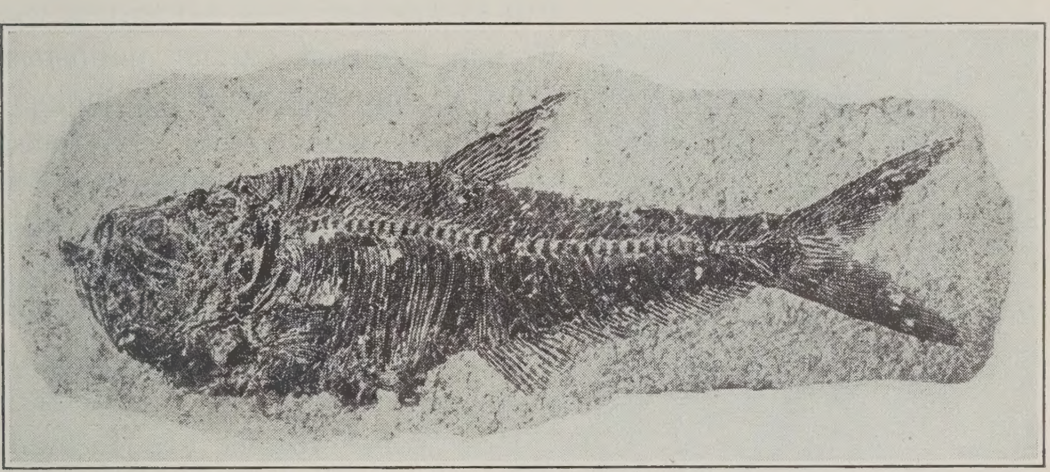
Courtesy Geol. Survey of Canada

FIG. 397. At one time these strata of rock must have been sand and mud under water. How do you know?

Sedimentary rock is formed in inland waters, too. There are many kinds of sedimentary rocks, depending on the proportions of sand, silt, or other materials which go into their composition. When the sediment is pure sand, sandstone results; when it is pure silt, or mud, the rock that forms is shale. Since the sand or silt is deposited in layers sedimentary rocks usually show layers, or *strata* (stray′ta). *Exercise 1.*

But there are other kinds of rock besides sedimentary rock. Some kinds formed when the lava of volcanoes cooled and hardened. Others formed from melted rock that pushed up from deep down in the earth and then hardened. Such rocks are hard because the materials in them have been completely fused by the heat which melted them. They are called *igneous* (ig′nee-us — fire) rocks. Granite, a hard mixture of closely fused black and white material, is an example of an igneous rock.

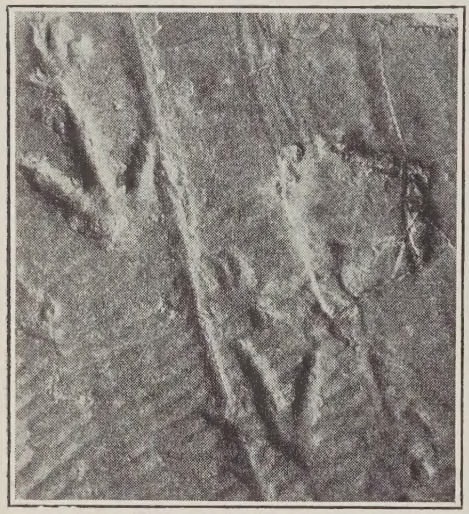
When the surface of the earth is raised or lowered by great movements of its crust the igneous and sedimentary rocks are crushed and twisted. Not only is the pressure terrific but much heat is generated. This, too, acts on the rock, often completely changing its structure. Sometimes the weight of rock or water above is enough to cause changes. The term *metamorphic* is used to describe all these changed rocks, so that besides the characteristic sedimentary rocks (such as sandstone) and the igneous rocks (such as granite) there are many kinds of metamorphic rocks. Marble is one of these. It was once limestone, a sedimentary rock, but has become so changed that it is no longer a sedimentary rock. *Exercise 2.*



Courtesy U. S. Geological Survey

FIG. 398. How can you explain these structures in a rock?

Man's first acquaintance with living things of the past. Since sedimentary rocks are formed from deposits of sand or mud, the remains of plants and animals that died in the sand or mud are sometimes included in the rock. Such remains are known as *fossils* from the Latin word "to dig." This name was given to them because they are dug out of the earth. Fossils had been found in many parts of the world long before scientists understood the process of erosion and the formation of sedimentary rock. You can well imagine the confusion of the early scientists at finding stone animals and plants! To be sure, the old Greek philosophers recognized them as the actual remains of animals of the past and the great Italian scientist and artist of the fifteenth century, Leonardo da Vinci, understood that the bones found in the rock must have come from animals that had once lived and had died during the time the rock was being formed. But it was not until 1812 when the French biologist Cuvier published his work on fossils that the biological world was wholly convinced that fossils were the remains of living things of the past. At this time the science of *paleontology* (pay′lee-on-tol′o-gee) was founded. This is the study of living things of past ages.



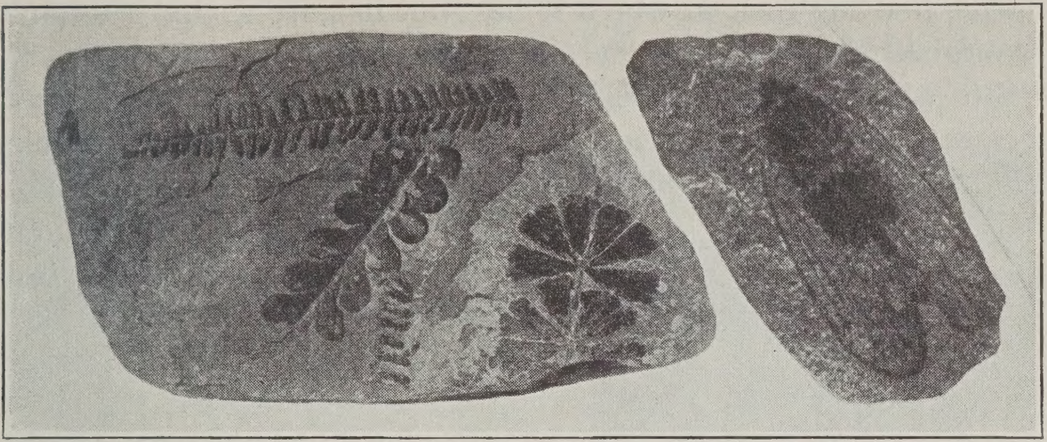
Courtesy Am. Mus. Nat. Hist.

FIG. 399. Dinosaur footprints hardened in stone. From a quarry in West Orange, N. J.

How some fossils are formed. An organism that dies in the water or near its edge settles on the mud or sand. Imprints will be left in the soft mud that later turns to rock. The hardening of the rock does not always spoil the accuracy of the impression, so that invertebrates as soft as the jellyfish and plants as delicate as the Algae occasionally appear in the rocks as sharp molds that might have been made by an artist. Even footprints in the muddy flats near some lake or stream have been preserved from bygone ages.

Coal is particularly rich in fossil imprints. Since coal was formed from the drowned bodies of millions of plants, coal fossils are mostly the remains of plants. So well have they survived the pressure and chemical changes that produced the coal that the smallest leaves and branches are clearly outlined.

Sometimes, as the organism dies it becomes buried in the mud or sand that is always being deposited. In time the softer parts will decay and disappear, leaving such hard parts as shells, spines,

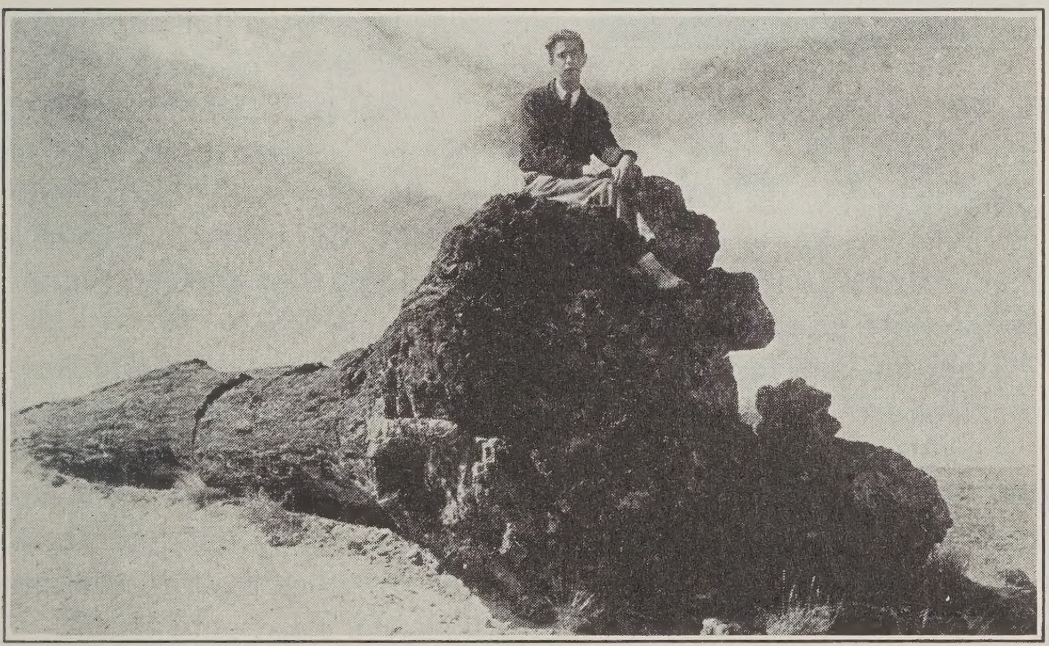


Courtesy Ward's Nat. Science Establishment

Fig. 400. Plant and animal fossil imprints found in Pennsylvania. Some of these fernlike plants are much like existing ferns.

teeth or bones embedded in the hardening rock. These remain in the rock as fossils.

As the rock hardens, the parts of the embedded plant or animal slowly change. Even some of the hard parts slowly dissolve away while mineral matter of various kinds filters in and replaces them. This is called *petrifaction.* When petrifaction is completed the bone or other hard part that was petrified is made of mineral

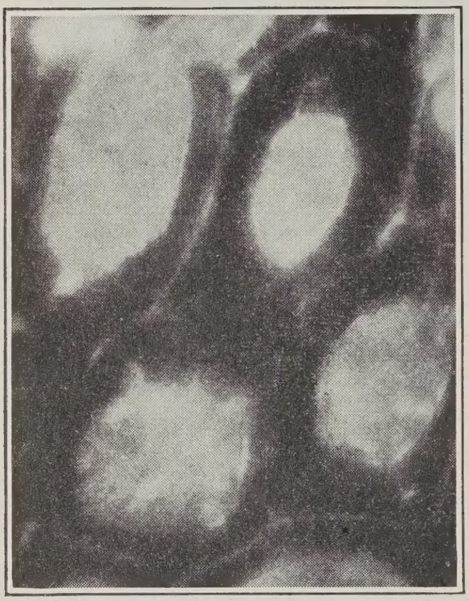


Courtesy U. S. Dept. of Interior

Fig. 401. Part of a petrified root and trunk from the Petrified Forest of Arizona. (*Photo by G. Grant.*)

matter like the rock in which it lies, but in spite of this it retains its original shape and general appearance.

But water with its deposit of wet sand or silt is not always necessary for the formation of fossils. Sometimes, though less frequently, sand, dust or volcanic ash may be blown over the body of an animal or plant. These materials, too, may harden into rock after long periods of time, thus embedding the hard parts of the organism. However, the most common fossils are the remains of water-living forms or of land-living forms that died on the shores of oceans, lakes, or streams.



Courtesy Ill. Geol. Survey

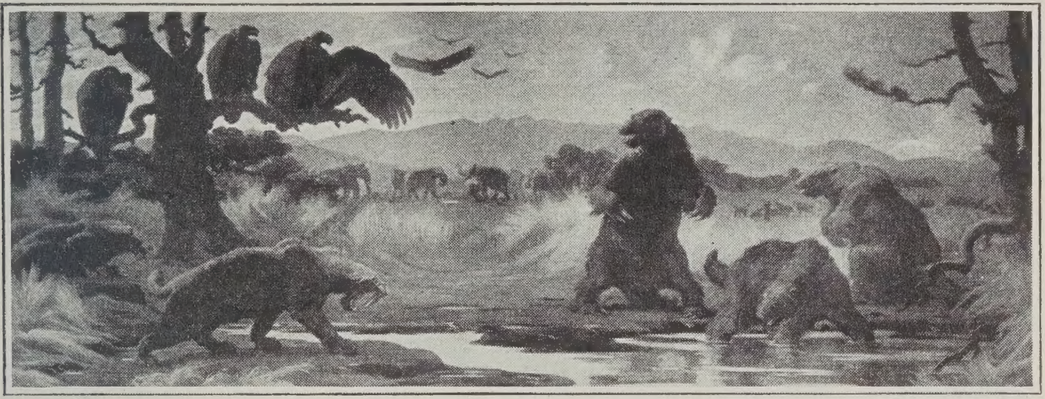
FIG. 402. A small piece of Illinois coal showing plant cells. This photograph was taken through the microscope.

Sometimes the remains of animals are piled so closely together that the mass forms the rock itself. In warm shallow seas vast rocks of limestone have been built up of the skeletons or shells of corals, of certain shelled protozoans, and of other forms. A small amount of sand or silt may be deposited with the shells. Of course, only the smaller animals live in such great numbers that their skeletons can produce great masses of rock.

Other types of fossils. There are remains of animals and plants in substances other than rocks. These, too, are called fossils if they are remains from bygone ages. Animals sank to their death and were preserved in pools of tar, such as are found near Los Angeles. Caught in the sticky tar or asphalt, they could not draw themselves out. The flesh gradually disappeared but the tar served to preserve the skeletons without the usual petrifaction.

Animals may be embedded in other preserving substances too. Ants crawling up and down the trunks of evergreens may be trapped in the sticky resin which oozes from the tree. Through the ages resin may harden into amber but the insect caught in the center of the mass remains unchanged. Enormous numbers of such fossils have been taken from the amber beds near the Baltic Sea.

From the icy bogs of northern Siberia, there have been recovered several bodies of mammoths, a type of woolly elephant no longer in existence today. The animals had been so perfectly preserved that dogs were able to eat the flesh. In the mouth of one was found the unchewed grass which it had cropped just before it fell into an ice crevasse (crack) thousands of years ago! Of course, fossils formed in this way are rare. *Exercises 3, 4.*

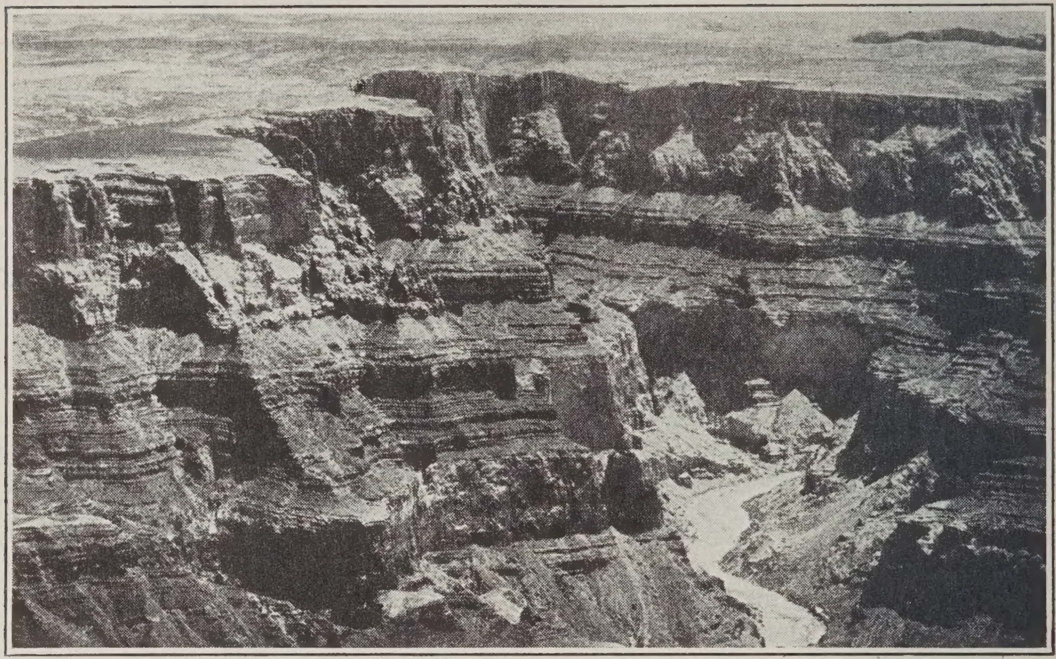


Courtesy American Museum of Natural History

FIG. 403. This painting by Charles R. Knight shows an ancient bear stuck in a tar pool. The saber-toothed tiger is ready to step in.

Fossil hunting. If fossils lie buried far below the surface of the earth because more and more sedimentary rock has formed above them, they are of no value to the paleontologist. No one knows what great fossil treasures may lie hidden beyond man's reach. Only those fossils near the surface are ever found. But fortunately there are several ways in which fossils become exposed. Sometimes a river cuts a deep channel through the rock as in the Grand Canyon of the Colorado. Thus walls of rock to a depth of thousands of feet are laid bare. Frequently, where a mountain chain has been uplifted, strata of rock have been broken through and the edges upturned and raised far above sea level. Strata millions of years old and thousands of feet deep are thus brought to the surface. This has happened in many parts of our country. Fossils of leaves or of small sea-living forms are so common in some regions that any boy or girl may find them.

When once the paleontologist has decided upon a region which, because of its formation, gives promise of containing fossils, an expedition may be equipped. A hardy company of men must be outfitted with tents and sleeping bags. They must be prepared for



Courtesy Aeronautical Chamber of Commerce of America

Fig. 404. The Grand Canyon of the Colorado. Ages after these strata of sedimentary rock had been laid down to form a plateau, the Colorado River gradually cut a channel through the rock.

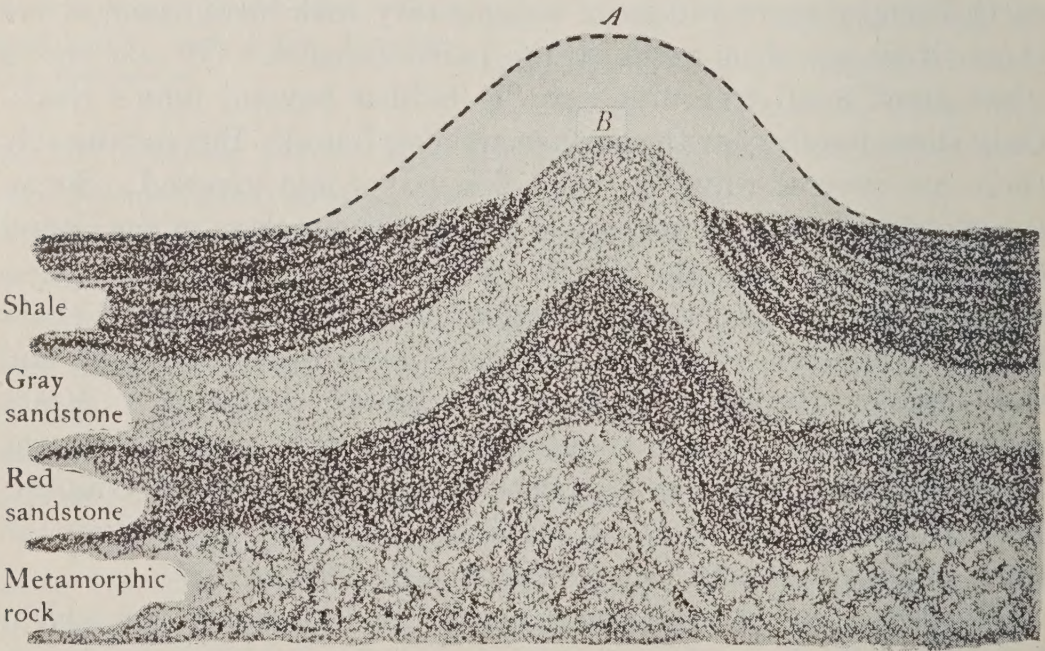
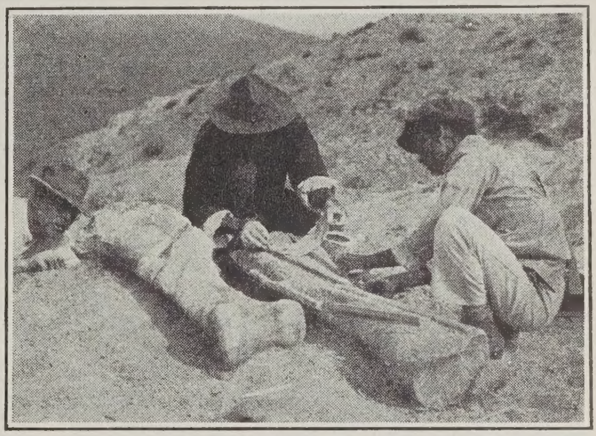

A
B
Shale
Gray sandstone
Red sandstone
Metamorphic rock

Fig. 405. A simplified diagram showing how ages ago a mountain (*A*) was pushed up. By erosion it was worn down to *B*. If you climbed this mountain, you might find on its slopes fossils that once were deep underground.

extremes of weather, drought, sandstorms, or floods. They must be hardened for tiring walks over desert land, for digging with bent backs in the glaring sun for many hours at a stretch. The company must include expert geographers, geologists, and photographers as well as paleontologists. One of the most famous of modern fossil hunters is Roy Chapman Andrews, who has led several expeditions for the American Museum of Natural History, New York City. Some of Dr. Andrews's most interesting expeditions have taken him to the Gobi Desert in Asia, where there have been found some of the reptiles known as dinosaurs as well as animals of other kinds.

Recent expeditions have carried motion picture outfits so that it is now possible to see the men in action. You can see the caravan of motor trucks loaded for the trip, the happy scenes in camp after the hard day's work. You can see the men scattered far and wide, closely searching the exposed layers of rocks for signs of a bone, waving their arms in excitement when they are fortunate in their search. You can watch them as they are engaged in the most painstaking task of removing the petrified and often fragile fragments of bone; how they wrap the loose pieces carefully in soft paper and soak the larger bones with shellac, encase them in bandages of plaster of paris and burlap or other supporting material, and label them for shipment. While this is in progress the geographers and geologists are engaged in a study of the strata so that the most careful notes may be kept of the position of the fossils in the rocks. The photographers, too, are at work preparing records.

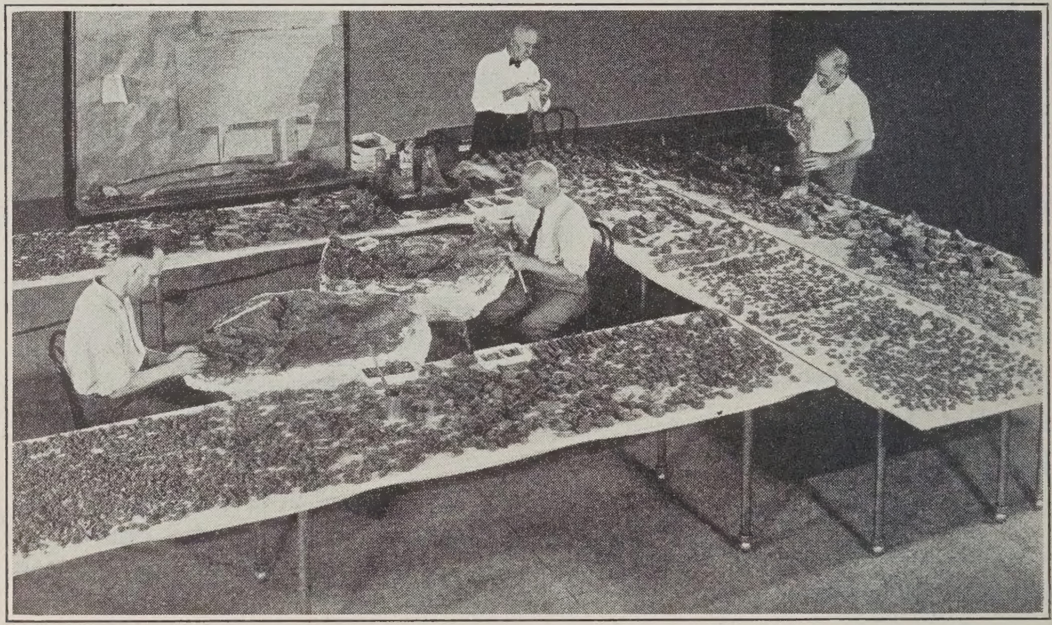


Courtesy Am. Mus. Nat. Hist.

Fig. 406. Chinese boys helping the scientist to cover up gigantic bones with burlap and flour paste so that they may be shipped without fear of breakage.

When the expedition returns only a small part of the work has been done. The real job is performed months later when the specimens are unpacked in the laboratory, cleaned of the bits of rock clinging to them, measured, described, and compared with other specimens.

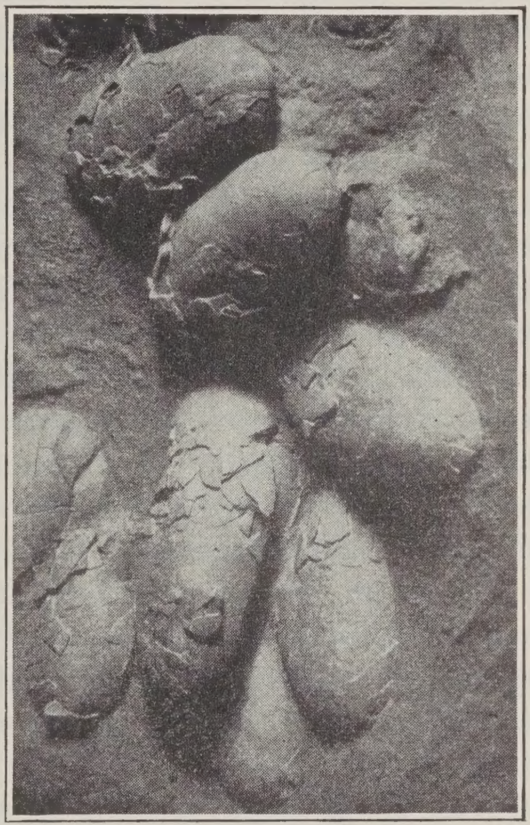
Reconstructing the organism from its remains. In ordinary fossil beds, such as those of the Gobi Desert and Wyoming, it is usually only separate bones or pieces of bone that are found. The ligaments that held the bones together in life have disappeared. Sometimes the bones are all found close together; more often they have been shifted in position so that they are widely scattered; many are completely lost. In the laboratory the bones are first carefully unwrapped, examined by experts, and then assembled. Missing bones must be replaced by models. For example, if the fossil bones of the left foreleg are missing, the right foreleg is used as a guide when a model is prepared. Often, some of the many vertebrae of the spinal column cannot be found. It is comparatively easy to make artificial vertebrae which are accurate in structure. If you examine the skeletons of fossils as set up in museums you will discover many such additions. They are often colored differently so that the visitor will not be misled.



Courtesy American Museum of Natural History

FIG. 407. It takes an expert to identify and piece together the fossil fragments sent home by an expedition.

After the assembling of the bones of the skeleton comes the more difficult task of reconstructing the rest of the animal. This task requires biologists who have made a most complete study of animal structure. They examine the fossil bones with great care to determine at what points muscles must have been attached. Being experts, they can determine, furthermore, about how large those muscles must have been. Then the thickness of softer tissues is carefully calculated. From such studies there develops a model of the animal as it probably looked when alive, millions of years ago.



Courtesy Am. Mus. Nat. Hist.

FIG. 408. A few of the petrified eggs where they were laid by a dinosaur ages ago. These were found in the Gobi Desert.

The age of the sedimentary rocks. From what you have read of sedimentation and erosion, of sand and mud hardening into rock, of remains of living things being slowly petrified, you probably realize that much of the rock and many of the fossils must be very old.

Through careful estimates made in many places and at many times it has been calculated that sedimentary rock accumulates at an average rate of one foot in 880 years.

Turn to the diagram which appears at the bottom of page 624. In this diagram several strata of rock are shown. If you assume that the layer of shale is 1000 feet thick, it will have taken 880,000 years to deposit that layer. Since the layer of gray sandstone is below the layer of shale, evidently it must have been deposited earlier than the shale, or more than 880,000 years ago. Estimates such as the above are sometimes used in calculating the ages of the rocks. This method, however, is not so exact as others that have been developed.

Another method of calculating the age of some sedimentary rocks has been to calculate the age of the oceans. All water that falls to the earth is fresh, not salt. By absorbing minerals from the soil it becomes salt. As rivers continue to add their slightly salty waters to the ocean and water evaporates from the surface of the sea the salt sea continually becomes saltier. By calculating the amount of salt in the ocean and the rate at which the oceans grow saltier as their water evaporates, geologists can calculate how long this has been going on; that is, how old the ocean is.

These methods have not satisfied geologists, however, because the possibility of error is so great. Recently a far more accurate method of calculating the age of the rocks was discovered; but it can be used with certain rocks only. In some parts of the earth there are rocks which contain the "radio-active" substances, such as the element uranium. Uranium gradually changes into lead at a rate which is known and which is always the same. When once the lead has been formed it remains in the rock and does not change any further. Thus by calculating the proportion of lead and uranium in such rocks one can tell for how long a time uranium in these rocks has been changing to lead or, in other words, for how long a time these rocks have been in existence. All these various estimates would make the first sedimentary rocks between two and three billion (thousand million) years old.

Of course, estimates arrived at in these and similar ways are crude. They are useful because the periods of time are so long, measured in millions of years, that errors of a few millions of years are unimportant. More accurate estimates are sometimes available for short periods.

How the geologist reckons time. For convenience the geologist has divided the vast stretch of time since the formation of the earth into several *eras,* each of which is marked by certain kinds of rocks or fossils. The first era started about three billion (3,000,000,000) years ago and lasted for about a billion (1,000,000,000) years. This was the era of no life (Azoic era). Then life appeared. Little is known of the life of this second era which lasted about another billion (1,000,000,000) years (Archeozoic era).

After this enormously long time came another era that may be called the Era of the First Fossils (Proterozoic era). This era lasted for more than 500 million years. In the younger rocks of this era there appear the fossils of many types of invertebrates. But fossils are scarce in these rocks. Both this era and the era that came before it were once thought to have no fossils at all.

For that reason the next era, which began about 500 million years ago and lasted for 300 million years, was called the Era of Ancient Life (Paleozoic era). In the earliest rocks of this era and in all the rocks following there are large numbers of fossils. The Era of Middle Life (Mesozoic era) followed. It lasted for about 140 million years. Its sedimentary rocks, too, are rich in fossils.

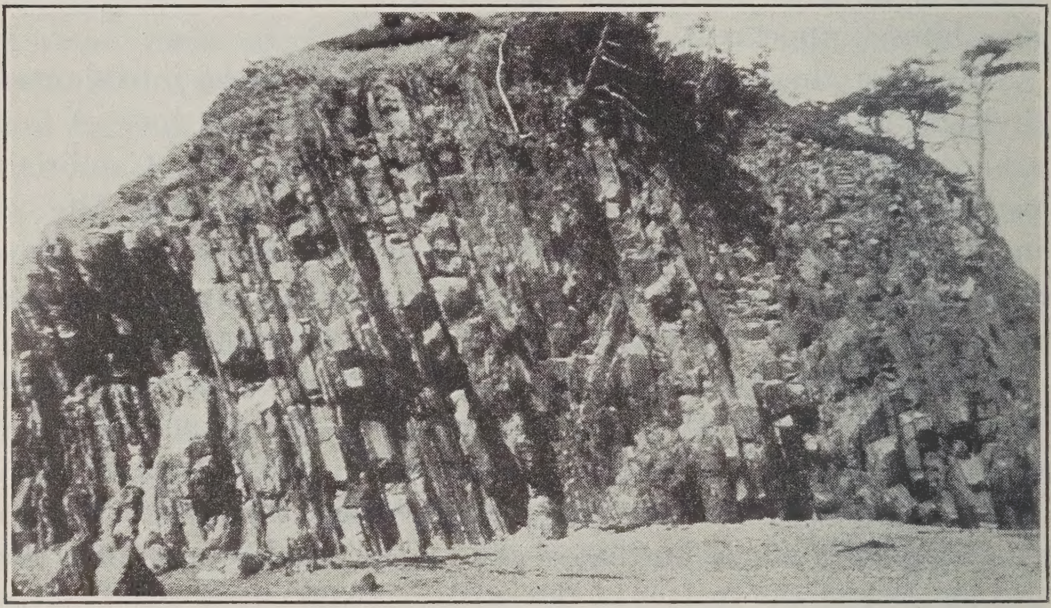
The Era of Modern Life (Cenozoic era) is the last and therefore the youngest. It is the era in which you now live. It began about 60 million years ago. It was during this era that the most modern types of animals and plants appeared. During its later stages man himself appeared.

Of course, the geologist has split these lengthy eras into shorter divisions of time, called *periods.* These have names, too. A few are important enough to remember. For example, the Cambrian period, which is the first period in the Era of Ancient Life, is important because all the preceding or older rocks are called Pre-Cambrian. This is done because the older rocks have so few fossils. The rocks of the Cambrian period have a great many.

How scientists reconstruct the past history of the earth. Sometimes, when the strata of sedimentary rock are lying in regular order, it is easy to discover which came first. It is like examining a book. There are distinct chapters, they are called strata; the first chapter is at the bottom of the pile of sedimentary rock, the last chapter at the surface of the earth. If you closed this biology book and laid it down with its front cover against the table the first page, the one first written or the oldest, would be at the bottom of the pile of pages, the last one would be on top. Now if Chapter I were printed on white paper, Chapter II on blue paper, and each succeeding chapter on paper of a different color you would see many distinct layers, some thick and some thin. However they lie, differences in the strata can usually be noted by the geologist as readily as you could see where one chapter ended and the next began if you glanced at the edges of a book in which each chapter was printed on paper of a different color. The rocks of the various strata differ because conditions were different when each layer was laid down and the materials are different.

Some strata are thick and took a long time to deposit, just as some chapters are thick and took a long time to write. In describing the length of a chapter in a book you say it contains twenty pages or fifty pages. You never measure it by the length of time it took to write. The geologist measures the earth's chapters (strata) in both ways. He may say that a stratum or layer is sixty feet thick; frequently he says it took fifty thousand years to deposit. As you already know, the time during which a series of rocks of a certain character was deposited is called a period.

This may lead you to think that reading the history of the earth is simple. But it is not, for, as a rule, the chapters do not follow one another in order; they have been squeezed out of place and the pages have been torn and destroyed. Because of the movements of the earth's crust the strata in most parts of the world are slanted and twisted instead of being horizontal. Sometimes, indeed, they have changed their position so many times that it is no longer possible for the geologist to determine where they belong. Masses of rocks of different kinds, chiefly metamorphic (those changed from their original state), are found piled on one another. Fossils, if ever they were present in the original rock, have been destroyed.



Courtesy Geological Survey of Canada

FIG. 409. These layers of sedimentary rock are very much alike in thickness, but what has happened to them? Could you tell which was older?

Sometimes the geologist depends on fossils to help him learn the correct order of the rocks. After he has worked out the order of strata containing fossils in one part of the world where the strata have been little disturbed he can use fossils for dating his rocks in another place where they are so mixed that he can no longer tell which is the older and which the younger.

The geologist and the paleontologist can join hands, therefore, in building up a picture of the earth as it was at any one period. The geologist is able to tell you something about the rocks that were present, the shapes of the continents, the mountain ranges, and rivers; the paleontologist can describe the animals and plants which lived in each period by reconstructing them from the fossils found in the layers of rock characteristic of the period. You will read next a description of the earth and its inhabitants at various stages in earth history. *Exercise 6.*

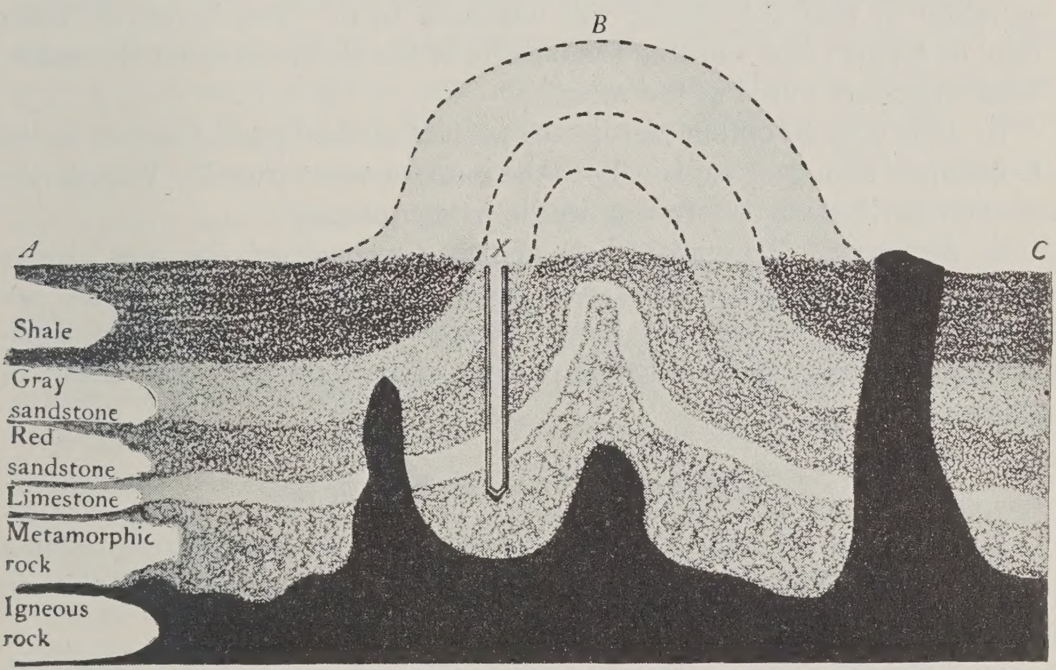


FIG. 410. Ages ago a mountain was pushed up at *B* and worn down (dotted lines). How does the geologist know this? If you were walking from *A* to *C*, what kinds of rock would you find? If a shaft is sunk at *X*, what further information is obtained? (A simplified diagram.)

Exercises

1. If a large, shallow, waterproof box is available you may watch sedimentation on a small scale. Send a stream of water carrying sand into one end of the box; the overflow can pass out the other end through an opening at the bottom of the side. What happens? Why? Now send water carrying mud into the box. Describe what happens. Explain.

2. *Demonstration of types of rock.* Examine samples of sedimentary, igneous, and metamorphic rocks. In general, which are the hardest? Which the softest?

3. Examine the different types of fossils provided in a standard set. Which are the unchanged remains of plants and animals? What kinds of changes may take place in the organism as fossilization goes on? Are there fossils which do not contain any part of the organism, changed or unchanged?

4. It is possible to imitate the formation of an imprint fossil by the use of plaster of paris. Use vaseline on the object (a scallop shell is suitable) so that the plaster will not stick to it. Two types of fossils may be formed, one showing the outside of the shell, the other the inside. Both types are found in the rocks.

5. It is easy to obtain pictures or posters of the Grand Canyon of the Colorado. Can you explain how the canyon was formed? Why is the canyon particularly interesting to the paleontologist?

6. *Summary.* To explain how man can reconstruct the past history of the earth you must know how rock is formed and how fossils are formed. Then you can show how the scientist puts together the information he obtains. What other important subject did you read about in this section?

Activities for the Junior Biologist

1. Start now to make a fossil collection. It may grow into something worth while. You will be surprised to learn how common fossils are in many parts of the country.

2. Read the books written by Carroll Lane Fenton and Roy Chapman Andrews. Report briefly to your class. (See index.)

3. Ask some of your classmates to join you in planning a make-believe fossil-hunting trip. How will you determine where to go? What sort of camping outfit will you need? (An experienced Boy Scout may be able to help.) What scientific instruments will you take along? Briefly describe your plans to the class.

4. There are many ways of indicating the comparative lengths of the eras of earth history. Devise a good way and demonstrate it to the class.

5. By reference to chemistry texts find out how scientists have measured the rate at which uranium becomes lead. Explain this briefly to the class. How does the scientist know that the lead came from uranium?

6. In E. M. Tappan's *Wonders of Science* read "My First Geological Excursion."

3. At Various Stages in Its History the Earth Presented Very Different Scenes

The forming of the earth. As you know, the earth is one of several planets revolving about the sun. This star, its planets, their moons and other small bodies which remain nearby are called the solar system.

There are several theories to account for the origin of the earth. One that is accepted by some astronomers is that another star passed the sun about three billion years ago. The distance between them was great, many thousand millions of miles, but the star was close enough to tear small and large bits of burning hot material out of the sun. The larger bits became the planets. They attracted to themselves all the smaller particles which were in their paths and increased in size rapidly. Ever since then the size of each planet has remained about the same. Then came the cooling of the planets, which took place with comparative speed.

On our planet, Earth, water appeared after a time. Many scientists believe this happened before the earth had cooled to its present temperature so that the oceans of those days must have been hot. And the rocks that rose above the seas were bare and ugly. When it rained, the downpour, as heavy as our cloudbursts, dashed down the steep slopes, for there was no soil and no vegetation to hold the water back. Pebbles and boulders (large rocks) were broken loose by the rushing waters; slowly they were ground up, forming sand or clay. Of course, there were no living things. They could not have existed on such a harsh, forbidding planet.

How the first living things might have appeared on this earth. In the beginning, as you saw, it was an unfriendly planet, without living things, swept by violent storms. The fiery sun, when it penetrated the clouds and mists, beat down on the earth. But the atmosphere was different; nowadays, little of the sun's ultraviolet light reaches the earth because it is blocked by the atmosphere; then, there was nothing in the atmosphere to absorb and remove the ultraviolet rays. Both rocks and sea must have been subjected to ages of sunlight different from ours. This is important. For the chemist knows that by using strong ultraviolet light on substances in warm water he can bring about important chemical changes: he can change certain complex compounds into even more complex compounds. It is possible, therefore, that in the warm seas of those ancient times substances of greater and greater complexity were formed under the influence of the strong ultraviolet light; this continued until, at last, there was formed the most complex substance — the substance that could reproduce itself; that is, living matter. *Exercise 1.*

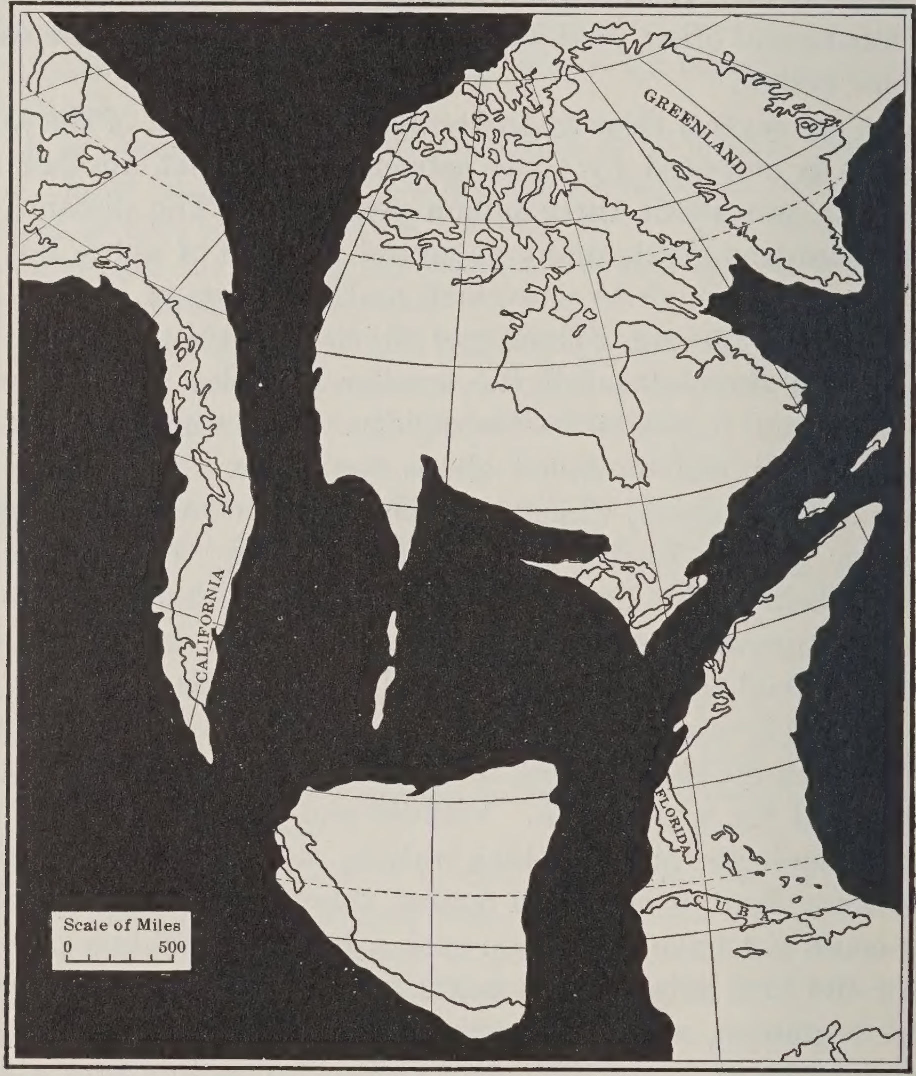


Fig. 411. A map of North America during an early period of the Paleozoic era. Seas shown in black. Can you find your own home town?

You have read that spontaneous generation has been disproved again and again by carefully controlled experiments. It may seem strange to you to find the idea presented just above. But you must realize that spontaneous generation may have occurred then although it no longer seems to occur. However, this is a theory; of course, man cannot know how life originated. There is only a small amount of evidence bearing on this problem and it is indirect. *Exercise 2.*

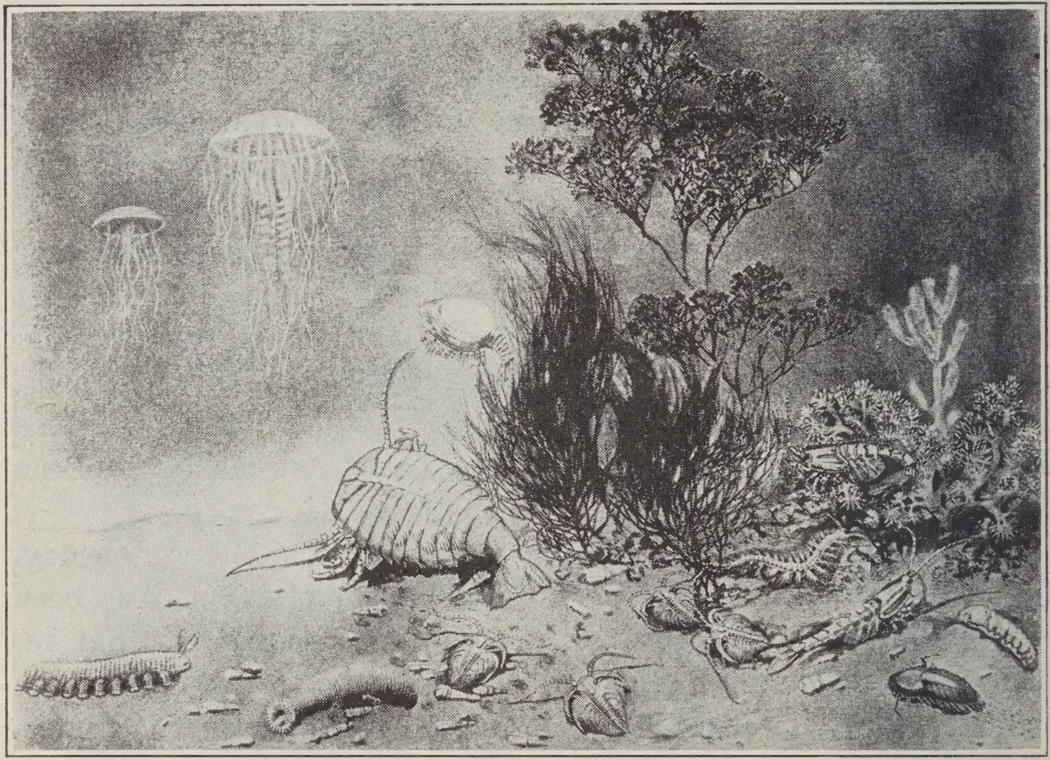
The earth for the next 1500 million years. After long ages of a planet without life the first blob (small mass) of living matter appeared, probably in the water. This happened about two billion years ago. The blob may have been microscopic, unicellular, colorless, perhaps like certain bacteria, those that build up their own food. Man does not know how it looked; he can only guess at its appearance, for when he turns to the earliest sedimentary rocks he finds no fossils to help him out. This is not astonishing, for these rocks are very old and they have been subjected to terrific pressure and heat.

Yet though he has not found fossils in these oldest of sedimentary rocks, the biologist is convinced that there was life on our planet during this ancient era (Archaeozoic). For those early rocks contain a substance known as graphite, the "lead" of your pencils. Graphite is a form of carbon that is produced only by living things. These very early rocks, therefore, show that there must have been life on the earth when they were being formed.

The rocks of the next era (Proterozoic) tell a different story. Fossils are present, but rare; no doubt most of them have been crushed beyond recognition or destroyed. Even those that remain are often hard to reconstruct. But the remains are unmistakable. They show that there were many kinds of living things, all of them water-dwelling forms. There were seaweeds of various kinds, and bacteria. Sponges existed then, sea-dwelling worms, and other kinds of simple invertebrates.

The earth and its inhabitants in the early Paleozoic era. About half a billion years ago the Paleozoic era (Era of Ancient Life) began. The rocks formed at that time are far richer in fossils than any that come before them and the biologist is able to reconstruct an interesting picture of the earth as it was then. An examination of the fossils shows not only what organisms lived on this earth but what they did and what sort of world they lived in.

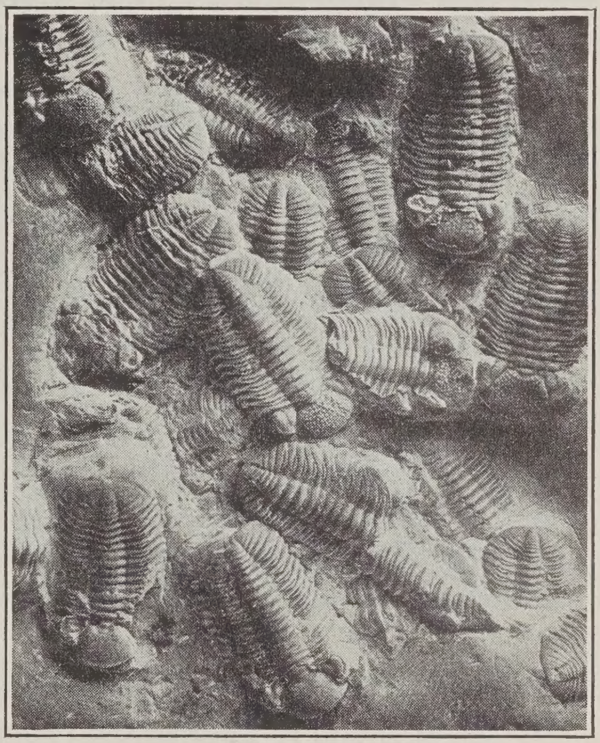
Life was still confined to the oceans and inland waters. The land had neither soil nor plants except perhaps where there were swampy shores at the edges of oceans, rivers, and lakes. The continents were smaller than they are now and vast seas covered much of the globe. There is reason to believe that the seas were warm from Newfoundland to the antarctic regions, for they were inhabited by little coral animals that built great reefs. Corals live only in warm waters. Seaweeds of many kinds floated in the oceans, serving as food for animals and as a source of oxygen. Jellyfish drifted on the waves and were washed up on the shore. Attached to the ocean bottom were sponges and animals that were five-rayed like our modern starfish group (Echinoderms); but they could not move about. Snails with uncoiled, cone-shaped shells crawled over the ocean sands; shrimplike creatures swam in the water. *Exercise 3.*



Courtesy Smithsonian Scientific Series, Inc.

FIG. 412. A Cambrian underwater scene. Which forms can you recognize? The large animal near the center is a giant trilobite.

So far it would seem that the picture of these early seas is much like a picture of a modern sea except that there were no fish. But when one stops to look more closely, each type of organism looks strange for it is not exactly like the modern types it resembles. And these seas were unlike ours in another way, for outnumbering and outranking all other forms of life was one that has since disappeared from the earth. It is known as a *trilobite* (try′lo-bite). It was a crustacean (lobster group), with feathered gills on its legs, three body regions, with a hard outside covering (exoskeleton), feelers, and compound eyes. Most trilobites were two or three inches long but some reached a size of two feet or more. Trilobites of many kinds crawled and swam in these busy seas. More species of trilobites seem to have existed then, as shown by their fossils, than of all the other kinds of animals together. For 100 million years they were supreme, so that this period (the Cambrian) is often spoken of as the age of trilobites. *Exercises 4, 5.*



Courtesy U. S. National Museum

FIG. 413. Trilobites. This gives you some idea of how crowded with trilobites the seas must have been.

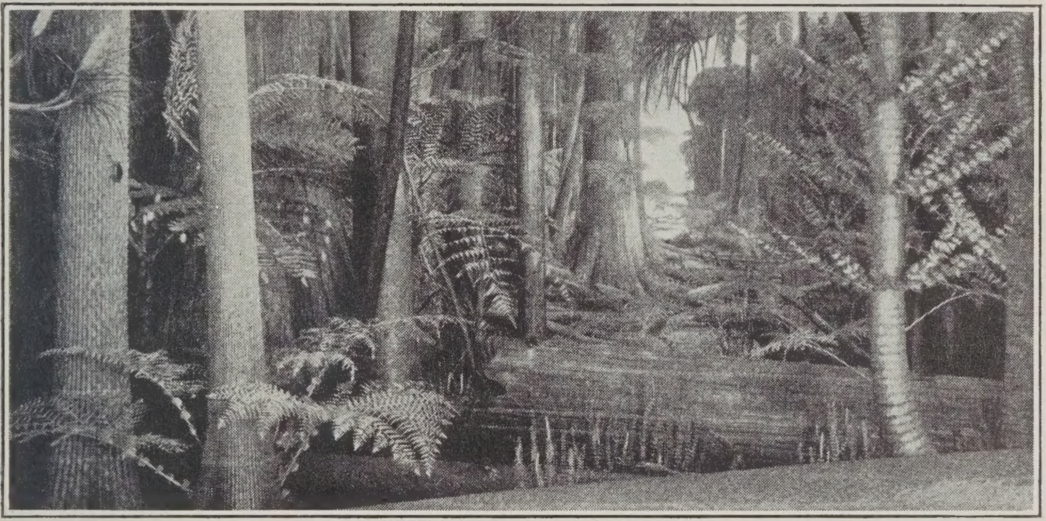
The earth during the formation of the coal measures. The journey you are taking through the ages of earth history is much like one undertaken at night in a thunderstorm; you cannot see the landscape until a flash of lightning makes it visible for a moment. By means of brief descriptions the earth and its inhabitants are being lighted up in just a few of the more important periods. All the in-between periods, extending over millions and millions of years, are not pictured here. It is not surprising, therefore, that when you next examine the landscape it should be very different from the one you have just read about; the changes occurred slowly, but many changes have taken place, for the planet has grown much older. Since you looked at the teeming sea life of the age of trilobites (Cambrian) and at the bare rocks of uninhabited continents, about 150 million years have passed; they are measured as several periods of geologic time. The era is still the Paleozoic, but it is the late Paleozoic, the period commonly called the *Carboniferous.*

The Carboniferous scene was different from the Cambrian. Fish are now present; in fact, soon after the age of trilobites, they were so plentiful and of so many types that one of the middle periods of the Paleozoic is often spoken of as the age of fishes. Soil covered the continents. Plants gave to the land the lush green color which you see in early spring. Wherever it was warm (and most of the earth had a mild climate) there were giant club mosses and huge tree ferns, fifty feet in height. In their shade were small ferns and mosses like those that now grow in moist places; there were conifers, ancestors of present-day evergreens, and a bewildering number of smaller plants living in almost tropical tangles. But in these dense forests you would have looked in vain for flowers; no lively colors relieved the monotony of leaf green because flowering plants had not yet appeared.

Through the vegetation crawled amphibians like our newts and salamanders. A few reptiles wandered about. Air-breathing animals much like present-day scorpions were present, and certain insects existed in enormous numbers. Many of them were larger than the insects of today. Some dragonflies had wings that measured a foot from tip to tip. There were cockroaches three to four inches long and they were of many types. At one time during this period there were so many species of cockroaches that biologists speak of an "Age of Cockroaches."

Here and there, in places now called Pennsylvania and England and the Saar Valley, there were enormous swamps. Some of them were salty, located near the ocean; others were inland, fresh water swamps. All had a thick growth of large plants; in time, all underwent tremendous changes. In the regions where these swamps were situated the earth sank slowly. As it sank water covered the swampy lowlands, drowned the plants, and covered them with a layer of sand or silt. When the continent rose again, it may have been only fifty or a hundred feet, a new swamp was formed, a new jungle of ancient plant life. But after the swamp developed the land sank again. This happened many times, until there were many layers of plants separated by many layers of sand or silt, all squeezed under the terrific pressure of the water and rock above. As millions of years marched on slowly the chemical changes occurring underground together with the pressure and heat changed those ancient plants to coal. It is the presence of these coal beds that gives the period its name, Carboniferous.

Today, when the paleontologist examines the coal beds he finds those alternate layers of coal and slate or sandstone, and in the coal are countless fossils of the plants of the great swamps. Their great trunks are sometimes upright in the coal bed; imprints of their leaves show up at the blow of the geologist's hammer. Many species of animals have also left their fossil remains in the rocks, so that biologists can picture the earth as it looked during the long ages of the Carboniferous period about 200 million years ago.



Courtesy Field Museum of Natural History

FIG. 414. A forest of the Carboniferous period. Ferns varied from small plants to huge trees. The animal on the tree to the left is a cockroach.

The age of reptiles. Again millions of years have slipped by. The Carboniferous period is behind you; you are now to view the earth during the middle era, the *Mesozoic*. The best estimates indicate that this era lasted for 140 million years. When it was young the climate was dry and cool; gradually higher temperatures and a more frequent rainfall prevailed. The age was rich in many kinds of plants and animals besides the reptiles that have provided its name. Ferns were common and so were mosses and the many kinds of Algae. Evergreens grew to huge proportions; remains of these Mesozoic trees can be seen petrified in Arizona. Before the era ended flowering plants were present, including the grasses and cereals which serve as food for herbivorous animals. During the age of reptiles, a few kinds of small mammals lived on the land, quite different from the mammals you know today; and some strange birds had appeared. These birds had feathers but they had teeth and a skull that looked like a crocodile's. The seas as before teemed with invertebrates of many kinds not unlike those you know; fish were common; the fresh waters contained amphibia. But, as the fossils show, all these animals did not compare in number or variety with the reptiles.

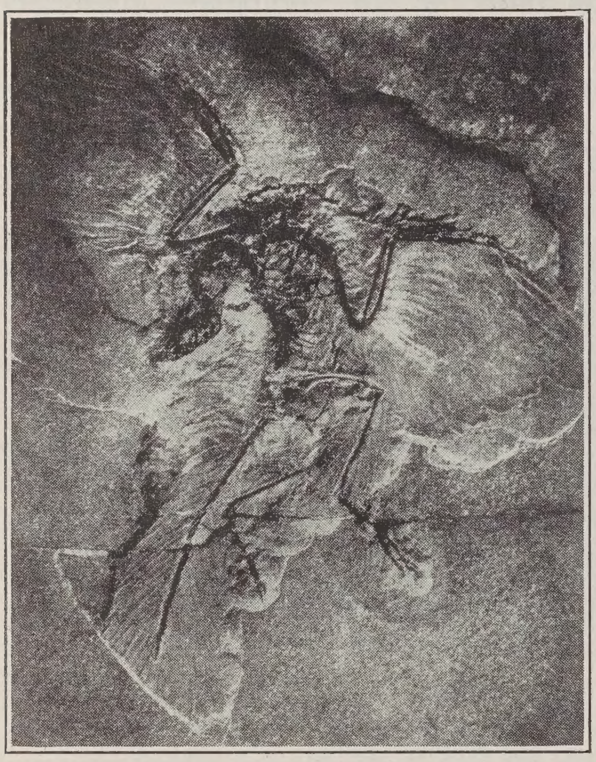
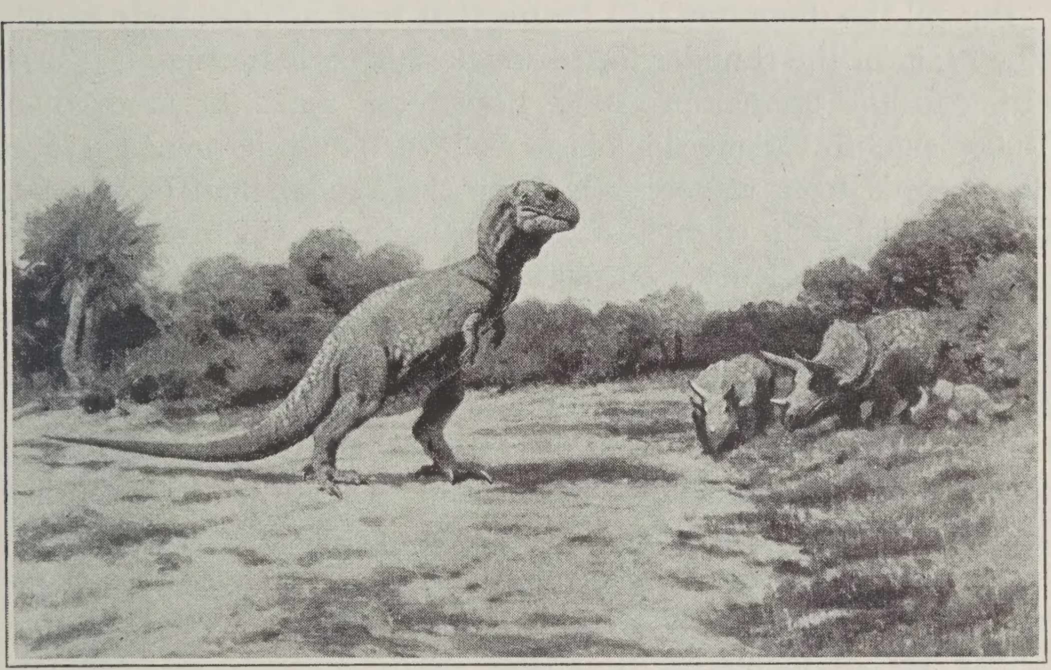

Courtesy Smithsonian Institution

FIG. 415. Imprint of a strange birdlike form (Archaeornis) which lived in the Mesozoic era. What evidence is there that it was birdlike?

To be sure, this was not the first appearance of reptiles on the earth; reptiles had roamed over the land during the coal age but they seem to have been small and far from numerous. Not until this era of increasing warmth and moisture did the reptiles find conditions suitable for such widespread development. In time they were so numerous and of so many different species that they completely dominated the scene. They ruled not only on the land, but in the sea and in the air, for many species had taken to the water and had become expert swimmers; others had developed wings. Some of these flying forms were as small as a robin, others were as large as a small aeroplane. The flying reptiles had their forelegs expanded into wings like those of the bats (mammals) of today. They have been called flying dragons because they were so much like the imaginary dragons of the fairy tales.

But of all the reptiles that ruled the earth during the age of reptiles the most interesting were the many representatives of the group known as *dinosaurs.* Among them were reptiles with queer shapes, huge bodies, and the most striking armor of bony plates.

A careful study of the structure of one of the giant dinosaurs, the thunder lizard (Brontosaurus), shows that it must have weighed about thirty-seven tons. Including the long tail, it reached a length of sixty-six feet. With legs like the columns of a building it apparently spent its time wading about in swamps and lakes. It was not a swimmer, but like many of its relatives it must have found movement easier in water because its great weight would be partly supported there. It browsed on plant life, eating about 300 pounds daily. Its teeth were poorly shaped for chewing and the presence of smooth, rounded stones within its fossil ribs indicates that plants were swallowed whole and then crushed in a gizzard in which the stones acted as grinders.



Courtesy American Museum of Natural History

FIG. 416. How the artist pictures the earth during the age of reptiles. *Tyrannosaurus rex* and three-horned dinosaurs (*Triceratops horridus*).

There were other plant-eating dinosaurs better fitted for defense. With heavily armored tails used as a weapon and bony plates over the head and shoulders these reptiles must have been mighty fighters. Their fossil bones show marks indicating that many bone fractures had occurred.

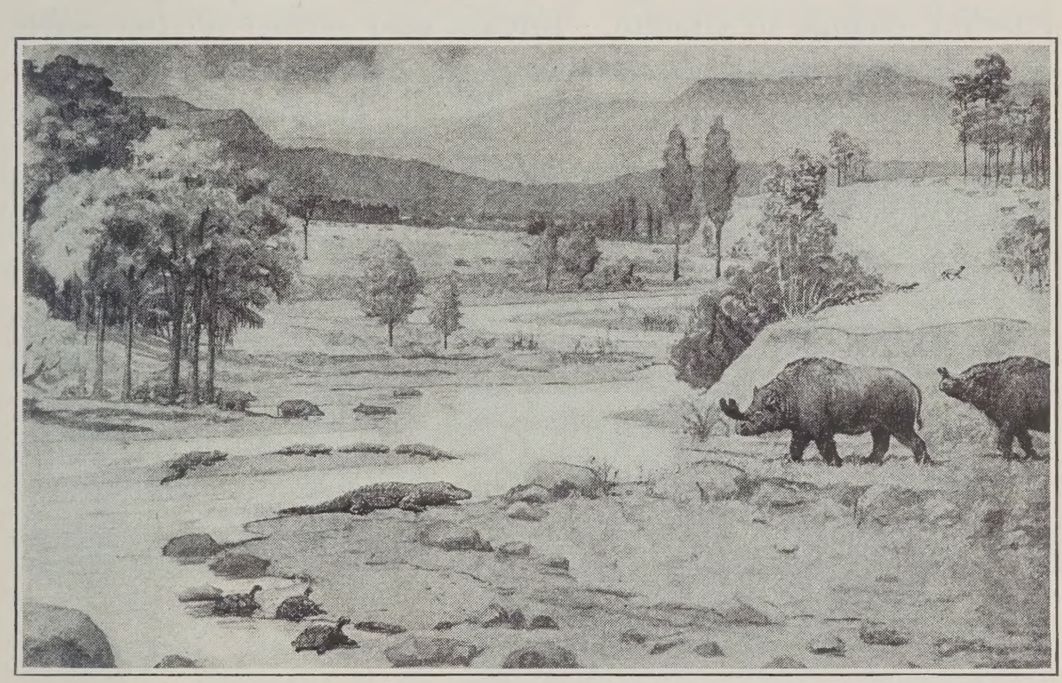
These dinosaurs had flesh-eating relatives. One such has been called the King Tyrant reptile (Tyrannosaurus rex) because of its monstrous body and its enormous mouth armed with great teeth. Like most of the flesh eaters it had small front limbs, probably used to hold prey, and strong hind legs for running or jumping. The powerful tail apparently helped to balance the body. Not all meat-eating dinosaurs were so large. Small, swift-footed forms were not uncommon, some no larger than a cat. *Exercise 6.*

But all the dinosaurs had brains that were astonishingly small. The brain of the thunder lizard weighed little more than a pound although the animal probably tipped the scales at more than 70,000 pounds. Some biologists believe that this mighty group disappeared from the earth because the animals had too poor a nervous system to compete with the mammals which were gradually appearing. Then, too, as the swamps dried up and the air grew colder conditions were less favorable for cold-blooded reptiles. No one, of course, knows what happened. The fact remains that for almost 100 million years dinosaurs, which inhabited all continents, were the masters on this earth and then they disappeared; for in the rocks of the next era not a single fossil of these reptiles has been found. The race died out completely in what seems to us like a sudden catastrophe. Actually it must have taken thousands and thousands of years before they became extinct.

The age of mammals (Cenozoic era). The age of mammals started 60 million years ago and its close brings you right down to the present or "recent" time, the time in which you live. At the dawn of this era the giant reptiles had vanished from the earth. The mammals, which had appeared at an earlier time, were still not very numerous and they were small and all more or less alike. But by the latter half of the era they had multiplied enormously and gradually had come to inhabit not only the land but the oceans as well and even the air. Some had taken to living underground, some in trees, some on river banks, others on dry grassy plains. Some were fitted to feed on insects, others on fruit, some on fish, others on grasses, and still others on the flesh of mammals. There are more than 7000 different species of mammals living now and there was a time when there were thousands of other species; these have died out.

Over our western and mid-western states (Nebraska, Montana, and Texas), during the second half of the era, there roamed elephants, rhinoceroses, and camels together with horses, deer, and carnivorous animals.

At this time birds were common too; they were not unlike the birds you know today. Reptiles and amphibia were small and inconspicuous. Plants were much like those you see now. Flowers of various kinds bloomed in the open places. Evergreens and trees that shed their leaves grew in dense forests.



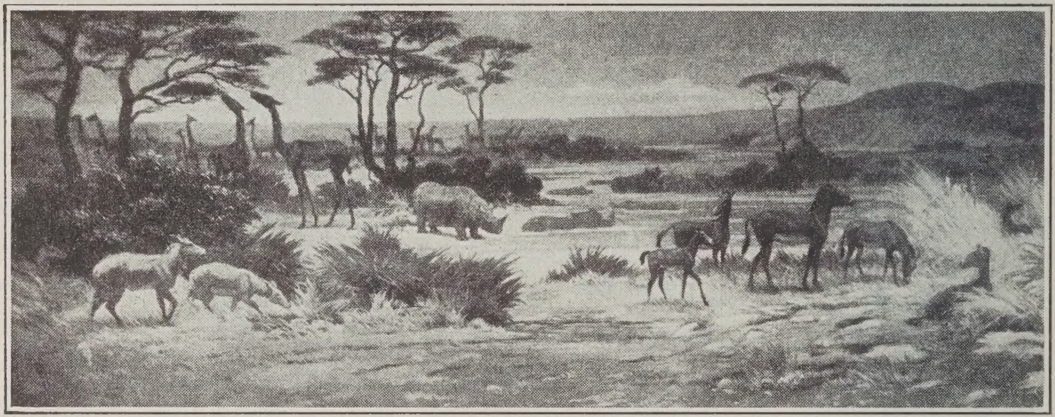
Courtesy Royal Ontario Museum, Toronto

FIG. 417. An early period in the age of mammals. Which reptiles do you recognize? How does the vegetation differ from that of earlier eras?

Although plants and animals looked more familiar, the earth itself looked very different. At the beginning of the Cenozoic era the Alps and the Himalayas had not yet been thrust up and all through this era the outlines of the continents changed from time to time. There was a broad land connection between North America and northern Asia and also between North America and northern Europe for a while during the early and middle part of this era. Since the climate was much warmer then than now many kinds of mammals inhabited the arctic regions and many forms roamed from one continent to another over the land bridges.

On the other hand, the land connection between North and South America was lacking during many periods, and the animals that lived in South America were different from those that inhabited any other part of the world.

When the glaciers came. On the whole the climate was warm and moist during the age of mammals, but gradually it grew drier and somewhat cooler. After millions of years had passed, at the very end of the era, there was an enormously interesting period which some scientists think lasted about two million years; it is called the Glacial Age (or Pleistocene); it showed a sharp and puzzling change in climate. Intense cold settled on the earth. Vast sheets of ice and snow covered the northern half of our continent and of Europe too. Rivers of ice or glaciers formed on the mountainsides where the hard-packed snow remained all the year and flowed down into the valleys miles below. Where they melted they formed glacial streams. You can see glaciers now but only where the mountains are very high and the climate, therefore, very cold. If the glacier ended in the sea big pieces of it broke off and floated away as huge icebergs. At the present time such icebergs form only in the far north. It is not known why the climate grew so cold at that time. But as the sheet of ice and snow moved down from the north living things retreated before this wall. The musk ox, now an inhabitant of the arctic regions, lived as far south as the present state of Oklahoma; the woolly mammoth was driven beyond the Ohio River; and the walrus lived off the shores of the present state of New Jersey. Mammals accustomed to warm climates were forced much farther south



Courtesy American Museum of Natural History

Fig. 418. Western Nebraska during the age of mammals. In those days horses roamed the plains. What other forms do you recognize?

or died of cold. Plants, of course, could not move; most of them perished. Then the climate changed; again the reason is not known. The glaciers, melting at their edges, retreated northward. Plants and animals followed them. And in time it grew far warmer than it is today. Lions and hippopotamuses roamed among the palm trees on the land that is now known as the British Isles.

Four times during this age the glaciers moved down from the north and each time they retreated. The evidence that they did so is clear, since every time the sheet moved it scratched the rock over which it lay. And each time it melted it left behind it the heaps of soil and rock it had carried or pushed along. Long Island, in the state of New York, has three such long mounds of ice sheet dumps.

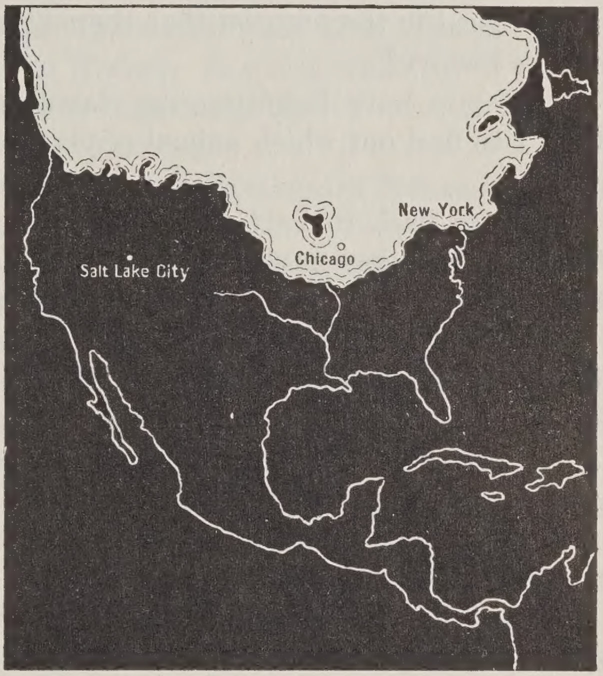


Fig. 419. How far south did the ice sheets extend? Glaciers are still to be seen in our western mountain ranges.

Change is continuous. Your hasty journey through geological time has taken you from the ages when this globe was without life to the times in which you live.

The glimpses you have had of the earth and its inhabitants in various periods of earth history have shown you scenes widely different from one another. Astounding changes took place; yet had you lived during any of the ages just described there would have been little sign of change, for a lifetime is too short to notice such changes. Could you see the earth again in another 100 million years you would find a different world, for changes are going on now as steadily as they ever did in the past. It is interesting to speculate what the earth will be like when it is twice as old as it is now. *Exercises 7, 8.*

Exercises

1. Look back to Redi's experiment on spontaneous generation. Could you duplicate his experiment? Why does not his experiment disprove what you have just read? What conditions might have been different then?

2. Can you explain what is meant by indirect evidence? What would be direct evidence for this theory?

3. What indirect or negative evidence is there that in the early Paleozoic era there were no land plants or animals? Why is this not as convincing as the evidence that starfish lived in the early Paleozoic? Why does it seem logical to the scientist that there was no soil in the early ages of the earth's history?

4. If you have forgotten the classification of animals look it up in Part 1 to find out which animal phyla were represented in the Paleozoic era.

5. Turn back to Part 1 and study the pictures of the animals mentioned in this section so that you can picture to yourself the life in the Cambrian seas. Why will your picture not be altogether accurate?

6. If you are near a museum you should visit it and write a report. If there is no museum near have the class secretary write to the Field Museum in Chicago, the American Museum of Natural History in New York, or to any other large museum in your vicinity for a price list of the publications and pictures bearing on the subject of the history of the earth. See how interesting a collection of pictures you can build up in this and other ways.

7. *Summary.* To summarize this section briefly, write a series of short paragraphs, one for each important stage in earth history. In each paragraph tell how the earth had changed since the preceding stage.

8. *Unit Summary.* Turn back to the unit statement. List the evidence to support it. You may need several columns. What headings will you give them? Check with the text to make sure you have not forgotten any important facts.

Activities for the Junior Biologist

1. Could you make models of prehistoric forms? You could use plasticine or soap.

2. If you can draw, you can make very interesting drawings of some of the scenes in earth history. Of course, you will have to do some reading first to be sure that you have correct information. Perhaps a friend could help you do some of the research. A mural showing the stages in earth history would be suitable for the halls or library.

3. If you like to write you can prepare an imaginary account of a trip backwards in time. A scientist and some of his students would have a thrilling experience in any of the past eras.

Good Books to Read

Bradley, J. H., *Autobiography of Earth.* Coward-McCann.
Daly, R. A., *Our Mobile Earth.* Scribner.
Fenton, C. L., *Life Long Ago.* Reynal and Hitchcock. *The World of Fossils.* Appleton-Century.
Fletcher, G. L., *Earth Science.* D. C. Heath.
Hobbs, W. H., *Earth Features and Their Meaning.* Macmillan.
Knight, C. R., *Before the Dawn of History.* McGraw-Hill.
Knowlton, F. H., *Plants of the Past.* Princeton Univ.
Lee, W. T., *Stories in Stone.* Van Nostrand.
Lucas, F. A., *Animals of the Past.* American Museum of Natural History.
Lull, R. S., *Fossils.* University Society.
Reed, M. and Lucas, J., *Animals on the March.* Harcourt, Brace.
Reed, W. M., *The Earth for Sam.* Harcourt, Brace.
Reeds, C. A., *The Earth.* University Society.
Robinson, W. W., *Ancient Animals. Beasts of the Tar Pits.* Macmillan.
Tarr, R. S. and von Engeln, O. D., *New Physical Geography.* Macmillan.
Wells, H. G., Huxley, J. S. and Wells, G. P., *The Science of Life.* Doubleday.
Whitnall, H. O., *A Parade of Ancient Animals.* Crowell.

UNIT XIII. THE ORGANISM IS THE PRODUCT OF ITS HEREDITY AND ENVIRONMENT WORKING TOGETHER

1. A Bridge of Protoplasm from Generation to Generation Results in Offspring of the Same General Kind as the Parents
2. The Transmission of Genes Results in Differences as well as Likenesses between Parents and Offspring
3. Some Differences between Parents and Offspring Are the Result of Changes in Genes and Chromosomes; These Breed True
4. Some Differences among Individuals of the Same Species Are Caused by the Environment

1. A Bridge of Protoplasm from Generation to Generation Results in Offspring of the Same General Kind as the Parents

The development of a new individual. The ameba splits into two equal parts, each of which grows into a new ameba; the yeast cell buds off a piece of itself and that piece grows up to be a yeast cell; the bread mold produces many little pieces of itself each of which is able to grow into a new mold. Those organisms that reproduce sexually follow the same general rule; only, in sexual reproduction a cell is separated from each of two parents; the two cells meet and conjugation or fertilization occurs. After fertilization, in a complex organism, the zygote undergoes a series of rapid divisions known as cleavage. In the case of the animal the cells arrange themselves in a hollow ball (blastula); one side pushes in and forms a cup (gastrula) and then differentiation begins. During this process the several kinds of tissue cells appear and the organs are formed out of various combinations of tissues. *Exercise 1.*

But while most cells are differentiating certain cells remain unchanged; they do not change into muscle, bone, nerve, or any other kind of tissue. They are set apart and remain inactive for a longer or shorter time. Eventually, if the animal develops normally, these cells develop into sex organs and produce eggs or sperms. A complex animal, therefore, is really composed of two main kinds of cells. There are the tissue cells that make up the body; they are called *somatic* cells, and the body itself is called the *soma.* The protoplasm of these tissue cells is called *somatoplasm.* The other cells are comparatively few in number; they are the cells that enter into reproduction. They are called *germ cells,* another name for reproductive cells, and their protoplasm is called *germplasm.*

The continuity of germplasm. The first biologist to present the idea that a complex animal was made up of two kinds of protoplasm, germplasm and somatoplasm, was August Weismann (1834–1914). More than forty years ago he called attention to the fact that both the germplasm and the somatoplasm of an animal come from the fertilized egg (zygote). Therefore, it is evident that germplasm (the zygote) produces both somatoplasm and more germplasm. This goes on in every generation and thus germplasm is passed on in an unbroken line. If the animal should die without having reproduced, that particular germplasm dies off and that line is broken. But under normal conditions the animal reproduces and germplasm is continued from generation to generation. Somatoplasm, however, is not immortal; every complex animal dies sooner or later. This is what Weismann meant when he spoke of the "continuity of germplasm." *Exercise 2.*

The bridge of germplasm. If there is continuity of germplasm there is an explanation for the resemblance between parents and offspring. But the reason for resemblance is not, as you may have assumed, that offspring come from the parents. Offspring really come from the germplasm carried by their parents. The parents themselves came from this germplasm. Offspring are like their parents because the bodies of both parents and offspring develop from the same germplasm. It may help you to think of it in this way: There is cat germplasm handed down from generation to generation. Cats do not really produce more cats; actually, both parents and offspring come from some of the same cat germplasm. In a similar way mouse germplasm produces mice, generation after generation. And this is true of other complex animals. "The parent is rather the trustee of the germplasm than the producer of the child" (Thomson). The germplasm known as the zygote (though it happens to be the fusion of two germplasms) serves as a bridge between parent and child. And a piece of this same germplasm serves as a bridge between that child and its child at some later time. The bridge of germplasm continues as long as the species exists. It is because of this bridge that the child looks like its parents.

Only part of the germplasm serves as the real bridge. The gametes in animals are so unlike one another, the large egg is so different from the tiny sperm, that biologists wondered how it could happen that the bridge connecting the male parent with the offspring should be so very much smaller than the bridge between the female and the child. A closer study of fertilization provided an answer. In some animals only the head of the sperm enters the egg. In cases in which the tail also enters, it seems to break up and disappear. Now the head of the sperm consists of little more than the nuclear material. And the nucleus, as you know, differs from the rest of the living matter in that it contains a substance known as chromatin. Thus it seemed probable that the chromatin material served as the bridge and was responsible for the offspring's looking like the parent.

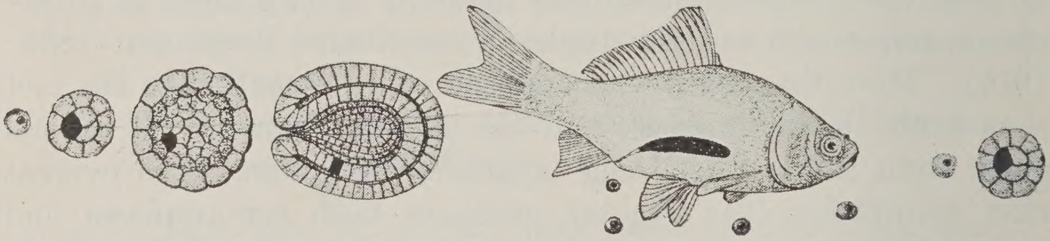
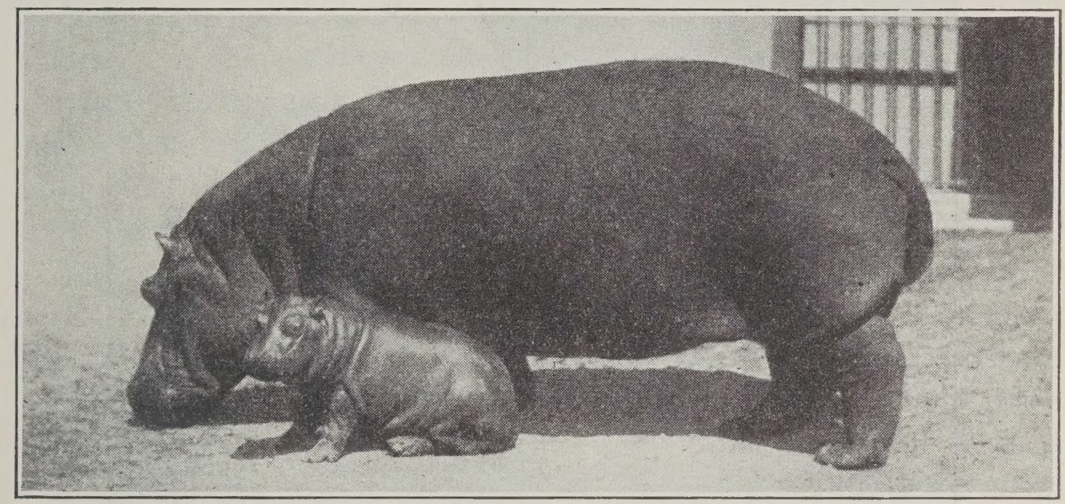


FIG. 420. A diagram showing continuity of germplasm in the fish. Starting with the zygote at the left trace the germplasm (shown in black) to the body of the fish. In what organ is it found in the adult fish? An egg from the fish, after fertilization, has formed the ball of cells at the right. What will this ball become? What will the "black" cell become?

Biologists have tested this belief by experiments; these showed that, in general, it is the chromatin of the nucleus that makes the child look like the parent. The chromatin is thus the real bridge between the generations.

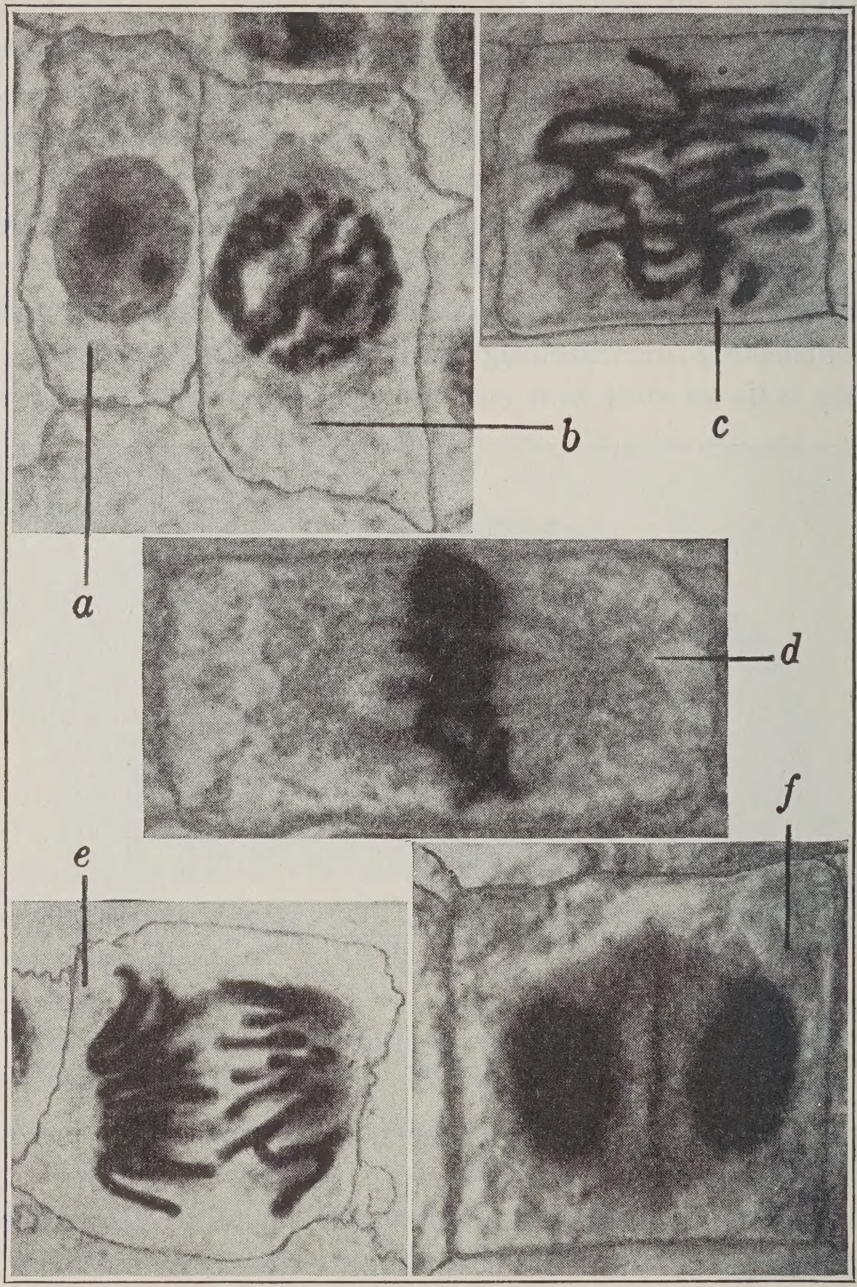
Behavior of the chromatin in cell division. Some years before biologists arrived at this conclusion, some interesting observations were made on the behavior of the chromatin of the nucleus during cell division. In the days when microscopes were first focused on dividing cells, some fifty years ago, it was necessary to kill and stain cells in order to study their division. Many cells in different stages of division had to be examined and the bits of information thus obtained had to be pieced together. Recently biologists have succeeded in watching the changes that go on in living, dividing cells so that you can now get a complete story of how the cell, and particularly the nucleus, behaves. This is what can be seen in a dividing cell:



Courtesy National Zoological Park

FIG. 421. Mother and child were formed from the same germplasm but at different times. What will happen to the somatoplasm of the mother eventually? If the child does not reproduce what will happen to its germplasm?

Before the cell divides, the chromatin seems to be strung out in tiny granules or threads throughout the nucleus. Then the chromatin material gathers together to form long thin threads which presently become shorter and thicker. These short pieces of chromatin are like rods, some straight and others bent into various shapes. They are called *chromosomes.* The chromosomes are jellylike in composition, yet so firm that they can be pushed around with a microneedle. In the living cell the chromosomes are not as distinct as they are when stained or drawn in a diagram but it can be seen that they are in pairs. Each pair differs to a greater or lesser extent from the other pairs in size and shape.



a, b — N. S. Kline; c, d, e, f — Gen. Biol. Supply House

FIG. 422. Stages in nuclear division (mitosis) in plant cells, stained. In (*a*) the nucleus is not dividing. In (*b*) the threads of chromatin have appeared; chromosomes are fully formed in (*c*). In (*d*) the chromosomes are lined up in the middle of the cell. They have already split lengthwise. The halves have separated in (*e*). In (*f*) the two new nuclei have begun to form. The dark line in the middle is the beginning of the new cell wall.

While the chromosomes are forming, the nuclear membrane disappears, so that the rest of the nuclear material becomes mixed with the cytoplasm. The chromosomes then move to the center of the cell. Each chromosome splits in two along its length, from end to end. When this has happened there are twice as many chromosomes in the cell as there had been originally. Next, the two halves of each chromosome are pulled or pushed apart until they are at opposite ends of the cell. If you counted the chromosomes at each end of the cell now you would find that the numbers are equal; and if you had counted the original number in the cell you would discover that there are as many chromosomes at each end as there were in the cell before the chromosomes split lengthwise.

A delicate membrane now forms around each group of chromosomes. In the meantime the chromosomes have changed into a chromatin network. Thus two new nuclei are formed, each like the nucleus from which it came. When the cell body splits shortly after this, cell division has been completed. Two daughter cells have taken the place of the mother cell. *Exercise 3.*

The whole process usually takes about half an hour. After some time, during which the chromatin must absorb food from the surrounding protoplasm, assimilate, and grow, each daughter cell goes through the same complicated process of division. Once more, chromosomes are formed, the same number as were formed when the mother cell began to divide; and each chromosome splits lengthwise, exactly down the middle. No matter how many times cell division takes place, each of the daughter cells will always get a part of the original chromatin material; and since new chromosomes form by the lengthwise splitting of the old the number will always be the same as in the mother cell. Thus all the cells that are formed will have not only the same number of chromosomes but also chromosomes exactly resembling those of the original cell in size and shape.

This complicated division of the nucleus is known as *mitosis* (mit-toe'sis). It occurs in practically all normal cases of cell division even in the simplest animals and plants. *Exercise 4.*

What stained cells show about nuclear division. A stained slide can be made of some rapidly growing tissue of an animal. By hunting over the slide you would probably find several cells that have just begun to divide, others that are near the end of the process, and many in the in-between stages. Of course, many of the cells will not be dividing, for not all the cells are of the same size and age, even within the same tissue. A careful search, perhaps over several slides, would enable you to put together the whole story told in the preceding paragraph. And in so doing you would discover that these stained cells show various structures that were not described before because they do not show clearly in the unstained, living cell.

One of these is the *spindle,* a structure of threads extending from one end of the cell to the other. The threads that make up the spindle seem to support the chromosomes. The chromosomes line up in the middle of the spindle. Apparently, after the chromosomes have split in half, the half chromosomes travel away from one another along the spindle threads. In cells which are near the end of division, the new groups of chromosomes are at opposite ends of the spindle.

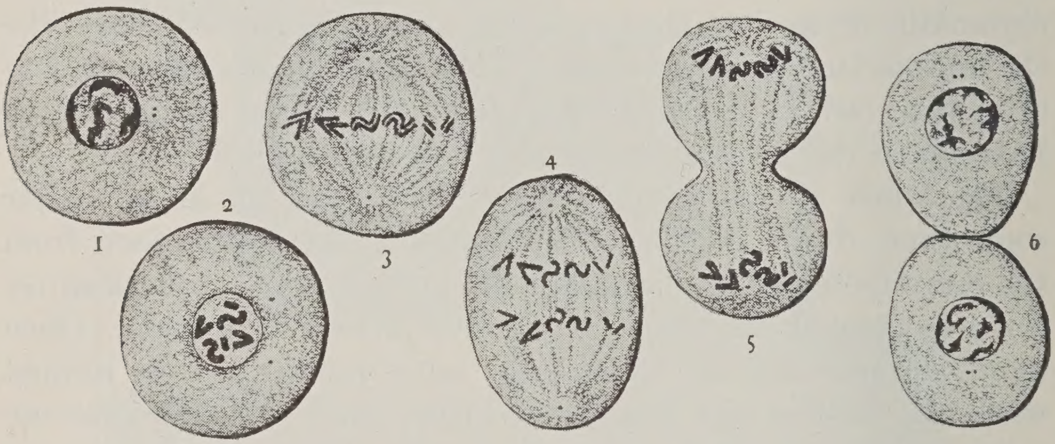


FIG. 423. Number 1 shows two tiny centrosomes near the nucleus. How many pairs of chromosomes are there in cell 2? How many chromosomes are there in each of the two cells about to form in number 5?

In the diagram of animal cell division you will see two centrosomes. These were produced by the splitting of the original single centrosome. The two centrosomes form the poles of the spindle; that is, the spindle threads seem to end near the centrosomes. Each centrosome seems to be the center of a star; not only the spindle threads but many other shorter threads radiate from it. In cells in which division is ending, the spindle and the rays about the centrosomes do not show up as clearly. The stained cell of course shows the important part of mitosis, too: the accurate halving of the chromosomes so that each new nucleus will have the same number of chromosomes, obtained from the lengthwise splitting of the original chromosomes.

Chromosome numbers. Were you to examine the dividing zygote of a leopard frog under the microscope you would see 26, or 13 pairs of, chromosomes. After this cell has divided again and again to form the many millions of cells of the frog's body each one of the cells will be provided with 26 chromosomes. That is what mitosis accomplishes. In other words, 26 chromosomes, or 13 pairs, is the number characteristic of the species, leopard frog. Every leopard frog has that number. And every species of animal and plant has its own characteristic number. Frequently, entirely different kinds of animals and plants happen to have the same number; for example, a starfish and a chicken both have 9 pairs or 18 chromosomes. But, though the number may be the same, the chromosomes must be quite different in two animals as different as the starfish and the chicken. *Exercise 5.*

Organism	Chromosomes	Organism	Chromosomes
Man	48	Onion	16
Monkey	48	Housefly	12
Frog (leopard frog)	26	Fruit fly	8
Maize (corn)	20	Chicken	18
Evening primrose	14	Starfish	18
Pea (garden pea)	14	Mosquito (Anopheles)	6

How the species number of chromosomes is kept constant. If the frog zygote with 26 (13 pairs) chromosomes grows into a young frog, it is evident that in time some of the cells will turn into eggs or sperm, depending on whether the new individual is a female or a male. Now if one of these eggs containing 26 chromosomes (13 pairs) were fertilized by a sperm with 26 chromosomes (13 pairs), the new zygote would start life with double the number characteristic of frogs. Should this happen the zygote would not develop into a normal frog and probably would not develop at all. Something must happen to keep the number of chromosomes from being doubled at this time otherwise the species number would change in each generation if the organism lived.

To understand how the number is kept from being doubled you must learn how the gametes are formed within the parent, for it is during this process that there is a reduction in the number of chromosomes. Before two gametes unite with one another in fertilization or conjugation the chromosome number in each has been reduced to one half the normal number. Biologists call the half number the *haploid* number; the full number before there has been any reduction is called the *diploid* number.

Formation of sperm in the higher animal. To understand how the sperm receives the haploid number of chromosomes you must go back for a moment to the formation of the spermary. During the time that muscle, bone, nerve, and other tissue cells become differentiated in the higher animal, the germplasm remains unchanged. Later, this undifferentiated germplasm becomes active. It divides and forms *primary sex cells.* There are many divisions, so that many primary sex cells are formed. Since the divisions are mitotic, each primary sex cell has the number of chromosomes characteristic of the species. As the young animal develops, the primary sex cells are surrounded by connective tissue as well as by other kinds of tissues. Thus the spermary is formed.

The individual is said to become mature when some of the primary sex cells go through a process called *maturation* during which they change into sperm. From time to time during the life of the individual more of the primary sex cells go through the same process. Although this process varies slightly in different animals there is always one essential step, a curious type of nuclear division in which the number of chromosomes is reduced by one half. This is called *reduction division.*

To understand the reduction division that occurs during the maturation of a gamete you must focus your attention on the fact that chromosomes are present in pairs. When reduction division begins the two members of each pair come close together. In doing this they may take curious shapes, they may even twist about one another but the joining (synapsis) is only temporary. Soon the members of each pair separate and move apart; they go to the opposite ends of the cell. Then the cell body divides. Each daughter cell gets only one member of each pair of chromosomes. It is in this way that the reduction in the number of chromosomes takes place. Each daughter nucleus after this reduction division has half the normal species number, the haploid number, consisting of one chromosome of each pair. Note that there is no splitting of the chromosomes in this division.

In the maturation of the sperm there are two other steps besides reduction division. There are a number of mitotic divisions and there is a change in the shape of the cell, giving it the appearance of the sperm. The mitotic divisions may occur in the primary sex cell before reduction division takes place or they may occur after the number of chromosomes has been reduced to one half. But whether mitosis take place before or after is unimportant for in either case mitotic division does not change the number of chromosomes in the cell; it only results in more cells. When maturation is completed, therefore, there will be a very large number of sperm cells and every sperm cell will, of course, contain one of every pair of chromosomes, that is, half the species number. *Exercise 6.*

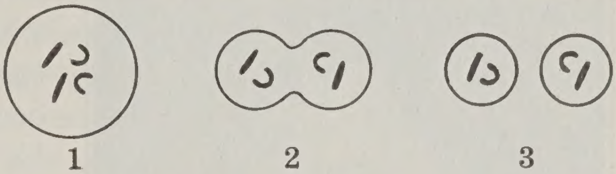


FIG. 424. Male primary sex cell going through reduction division. The nuclear membrane is not shown. How many chromosomes are there in 1? Note that one of each pair goes into each daughter cell.

Formation of female gametes in the animal. In the maturation of the egg there are also three steps, reduction division, mitotic division, and change in shape. But when the primary female sex cell goes through reduction division, producing the haploid nuclei, the cytoplasm divides unequally so that one daughter cell is large, the other small; and in the mitosis which follows, cytoplasmic division is again unequal. Of the four cells produced by these two divisions only one survives, the one that contains almost all the cytoplasm. This is the egg which, like the sperm, has only one of each pair of chromosomes. The other three are tiny, useless cells that disappear later. (They are called *polar bodies.*) In some animals the surviving cell stores large amounts of food material, called *yolk.* This increases its size still farther.

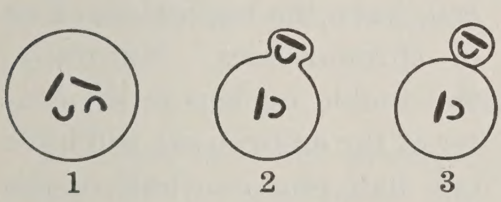
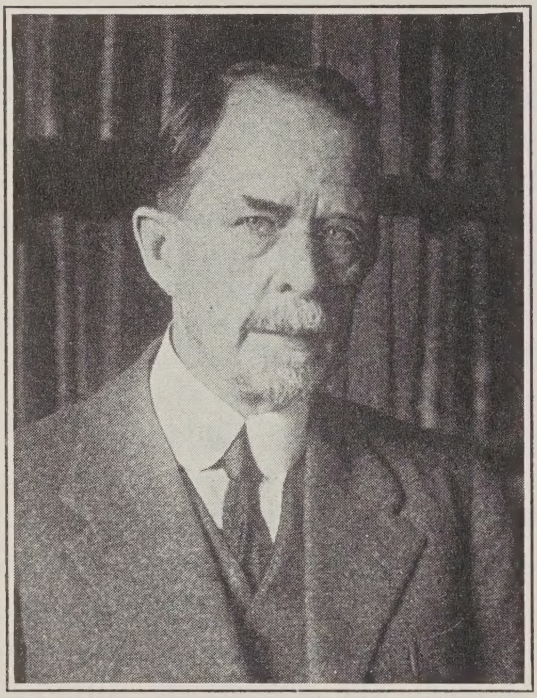


FIG. 425. Female primary sex cell going through reduction division. How does it differ from reduction division in the male?

Since both egg and sperm are haploid, a diploid zygote is formed when they unite in fertilization. Each pair of chromosomes in the zygote consists of one chromosome from the male parent and one from the female. Thus the species number is kept constant in each new generation. *Exercise 7.*

Reduction division in plants. Of course, reduction division must take place in the flowering plants and in other types of plants in which sexual reproduction takes place. If it did not, these organisms could not maintain their normal species numbers of chromosomes. In flowering plants, while the pollen is forming in the anther a reduction division occurs. When the pollen grain leaves the anther to settle on the stigma it is already *mature;* that is, its nucleus is haploid. When the nucleus of the grain divides later each daughter nucleus will be haploid (see Unit VII, Problem 4). The original embryo sac nucleus is already reduced, too; and all the eight cells which are usually formed within the embryo sac, including the single egg cell, have the haploid number of chromosomes. Naturally, the double nucleus in the center of the embryo sac will have one half plus one half or the diploid number. When it is fertilized later by one of the twin sperm nuclei its chromosome number will be one half plus one half plus one half (triploid), a most irregular number. But this irregularity is of no importance because the only cells that have this odd number are endosperm cells which are absorbed (eaten) by the developing baby plant.



Keystone View Co., N. Y.

FIG. 426. Thomas Hunt Morgan. During the first quarter of this century, while professor at Columbia University, Dr. Morgan developed the theory of the gene.

The composition of chromosomes. The chromosomes are the means by which the characteristics of the parents are passed on to the offspring. However, it is really the material of which chromosomes are composed, chromatin, that does this important work.

Years ago the best microscopes were turned on chromatin in an attempt to discover what it was. This was of little help, but recently a theory was advanced that the chromosomes must be composed of substances which bring about changes that result in the various characteristics of the organism. These substances are called *genes* (jeans). Since genes have never been seen with the microscope scientists cannot be sure that they exist. Professor Thomas Hunt Morgan is responsible for the theory of the gene. He and his students and hundreds of biologists in many parts of the world have been testing out the truth of the theory for the last twenty years. They are producing more and more evidence in support of it; you will learn of some of it in later pages.

Genes are supposed to be too small to be seen with the microscope; they are said to be *ultramicroscopic.* Their chemical make-up is also not known but certainly they must be substances that can assimilate, grow, and form more of their own kind. Biologists have come to the conclusion that genes are always arranged in a single row within the chromosome, like a string of beads. Because of this each gene is split in half whenever the chromosome splits lengthwise. Thus in mitosis each daughter cell gets not only half of every chromosome, but also one half of every gene. And in reproduction it is the sex cells with their chromatin made up of genes that serve as the bridge connecting each generation with the next. *Exercise 8.*

Exercises

1. If you have not already done so, study reproduction in Ameba, yeast, and the bread mold with the aid of the microscope. Review fertilization and development of the embryo in a complex animal.

2. Draw a dissected animal, such as a frog or fish, with mature sex organs. Using different colored crayons, shade in all the somatoplasm in one color; the germplasm in another color.

3. Illustrate mitosis by drawing a series of clear diagrams. Imagine that the cell has four chromosomes when chromosomes begin to form.

4. *Demonstration.* Mitosis in onion root tip (or similar material). Examine stained sections of onion root tips under the microscope. Can you find nuclei that are dividing? Can you find chromosomes? Draw or describe the chromatin material in cells that are at the beginning of division, in cells that are half through division, and in cells that are near the end of division. What structures do you find that have not been described?

5. Study the table of chromosome numbers. How can you explain the fact that the numbers are all even numbers? Can you draw any conclusions about the complexity of the organism and the number of chromosomes?

6. The mosquito has six chromosomes. Draw a series of diagrams to show the three steps in the maturation of its sperm.

7. By what mechanism is the primary sex cell given chromosomes exactly like those of the zygote? Explain and draw. Compare the chromosomes of a skin cell with those of the zygote and those of the primary sex cell. In what process is the number of chromosomes reduced to one half? Explain and draw. In what process is it restored to the full number?

8. *Summary.* What is meant by the bridge of protoplasm? Of what substance does the real bridge consist? How are chromosomes distributed to each body cell? To each sex cell? Of what are they composed? What happens to genes in mitosis? Now write a paragraph telling how the bridge produces offspring like the parents.

Activities for the Junior Biologist

1. Could you prepare a chart that would illustrate continuity of germplasm?

2. Mitosis and maturation can be shown best by means of movable chromosomes. You might make small wooden chromosomes of different shapes to be hung on a board. Draw the outlines of cells on the board and put in screw hooks on which to hang the chromosomes. This demonstration can be made in less permanent form by using paper chromosomes with thumb tacks. You might use small, painted bar magnets on a sheet of tin or iron.

3. There are many devices for making permanent models to illustrate the whole process of mitosis: the frame of a box might represent the cell wall; wires, the spindle; and so on.

4. An ambitious group project would be to plan a "dance of the chromosomes," in which mitosis and even reduction division could be shown.

5. If your school has a good slide showing mitosis in a root tip, photograph parts of it under low power. If your pictures are very good, enlarge them to make a mural.

2. The Transmission of Genes Results in Differences as well as Likenesses between Parents and Offspring

Differences between parents and offspring. You have learned why living things are always of the same general kind as their parents. But organisms of the same species also differ from one another in many ways. Some human beings have blond hair and blue eyes; some have black hair and brown eyes; and others have combinations of dark hair and blue eyes or blond hair and brown eyes. You may have noticed that sometimes one child of several in a family has blue eyes although both parents are brown-eyed. What is true of the human species is true of every other species, plant or animal.

You know that offspring are of the same general kind as their parents because they are produced from a part of the same germplasm that produced their parents. The genes that lie in the chromatin of human germplasm produce human beings; the genes that lie in the chromatin of the four-o'clock germplasm produce four-o'clock plants. But this is only part of the story of heredity. The complete story would have to show why brown-eyed parents may have blue-eyed children and why pink-flowered four-o'clock parents may have some red- and some white-flowered offspring.

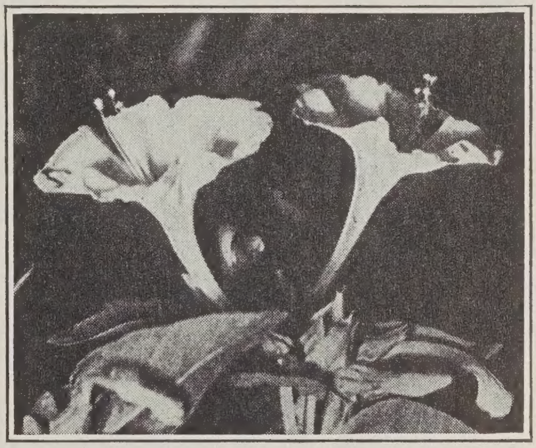
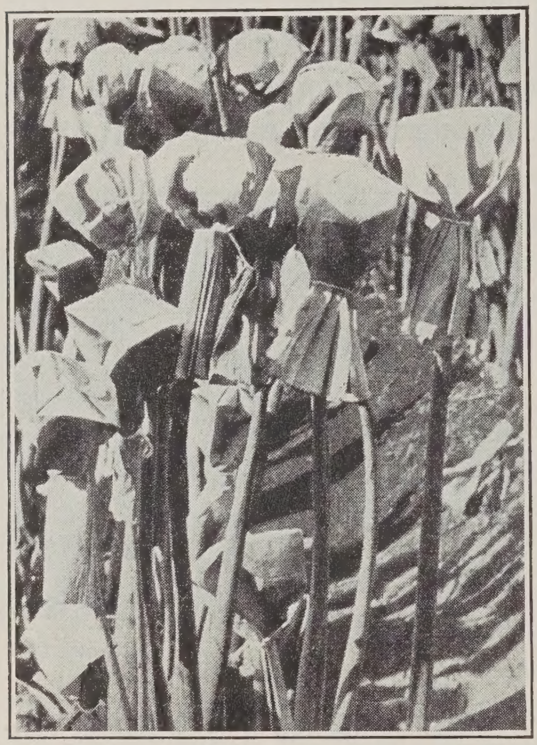


Photo by Frank Gehr

FIG. 427. The blossom of the four-o'clock. Some four-o'clock plants have red flowers; some, white; and some, pink.

The case of the four-o'clock. The characteristic (also called character) particularly studied in the four-o'clock was the color of the blossom. Some plants have red blossoms, others white. Redness and whiteness of blossoms are spoken of as a pair of *contrasting characters.*

Such red- and white-flowered four-o'clock plants were *crossed* (mated). The pollen from a white flower was transferred by hand to the pistil of a red flower on another plant. To make sure that there was no accidental pollination, which would spoil the experiment, the stamens of the flowers that were to receive the pollen were removed and the flowers covered with paper bags. Then they could not pollinate themselves and no foreign pollen could reach them. Fertilization occurred, the flowers withered, and the fruits and seeds developed under the paper bags. The biologist performing the experiments kept careful records so that the parentage of every seed was known. To make the experiment complete, red flowers were sometimes used as the pollen parent and white flowers as the ovule parent.



Courtesy U. S. Dept. of Agriculture

Fig. 428. The method used in an experiment with onion plants to prevent accidental pollination. Does this interfere with the healthy formation of fruit and seed? Explain.

The seeds that were produced from these fertilizations were planted the next season. When the plants grew up and bloomed their flowers were pink. No matter how often red four-o'clocks were crossed with white and no matter which kind of flower supplied the pollen and which the ovule, the offspring were always pink-flowered. The one parent contributed germplasm with a gene for determining red flowers; the other parent contributed germplasm with a gene for determining white flowers. Apparently when four-o'clock genes for red-floweredness and for white-floweredness are in the same zygote it develops into a plant with pink flowers.

These results probably do not surprise you. But the experiment was continued by crossing the pink-flowered plants and then a strange thing happened. The offspring, which were the grandchildren of the original plants in the experiment, were of three different kinds: some had pink flowers, like their parents; some had red flowers, like one grandparent; and some had white flowers, like the other grandparent. When the number of plants in the experiment was large about 25% of the offspring were white-flowered, about 50% were pink-flowered, and about 25% were red-flowered. This is a ratio of 1 : 2 : 1.

The experiment was continued by biologists. They crossed the red-flowered grandchildren with red-flowered grandchildren and discovered that nothing but red-flowered plants were produced. They crossed the white-flowered grandchildren with white-flowered grandchildren and found that only white-flowered plants appeared in the next generation. They crossed the pink-flowered grandchildren with pink-flowered grandchildren and discovered that they obtained the same 1 : 2 : 1 ratio of white-flowered to pink-flowered to red-flowered plants as had been produced when the pink-flowered children were crossed. *Exercise 1.*

Chromosomes and genes in the four-o'clock cross. Chromosomes carry the genes that determine the characters in organisms. Chromosomes are present in the zygote in pairs; one comes in with the sperm; the other is supplied by the egg. You know, too, that when division of the zygote occurs the nucleus divides by mitosis so that every cell of the new plant (or animal) has its chromosomes in pairs just like the original zygote. Therefore, every normal cell has two genes for determining a character; the father of the organism supplied a gene for that character and the mother supplied another gene for the same character. For example, every cell of the red-flowered plants had two genes for redness, making a pair. Genes are sometimes represented by letters. Thus a red-flowered plant can be represented by *RR*. The white-flowered plant can be described as *WW*.

A pink-flowered plant which comes from the crossing of a red flower with a white one obviously receives germplasm with a gene for redness from one parent and a gene for whiteness from the other parent. The zygote therefore contains one *R* and one *W* and all the somatic cells, since they form by mitosis, contain *R* and *W* also. The pink-flowered plant, therefore, has the make-up *RW*. The *RR* and *WW* plants are said to be *pure*, meaning that the pair of genes consists of two genes that are alike. The *RW* plant is not pure; it is known as a *hybrid*. A hybrid is an organism in which the two genes that make up a pair are different. You are so accustomed to thinking of a "pair" as two like things that it may seem strange to you to think of *R* and *W* as a pair. But you must remember that both *R* and *W* are genes for producing color of flower, and therefore they can well be considered a pair.

How biologists explain the 1:2:1 ratio. You will remember that when two pink-flowered four-o'clocks are crossed some of the offspring are red, some pink, and some white. If now you apply your knowledge of the behavior of the chromosomes during maturation and fertilization you will understand why such results are obtained when two hybrids are crossed.

When gametes are formed in the reduction division the two chromosomes that make up a pair part company. For example, when a primary sex cell of the pink-flowered hybrid *RW* goes through reduction division the gene *R* goes into one gamete and the *W* goes into the other gamete. The two can never be together in one gamete. Gametes, or sex cells, are always pure since they contain only one chromosome of a pair, and therefore only one gene of a pair. There are many primary sex cells and many gametes will be formed, and of all this number about half will contain the *R* gene and half the *W* gene. Under normal conditions when the gametes are ready for fertilization there will be about the same number of gametes containing *R* as there will be gametes containing *W*. *Exercise 2.*

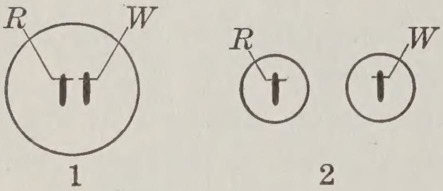


FIG. 429. Primary sex cell forming gametes. How many gametes with a gene for redness come from the primary sex cell? How many with a gene for whiteness? If there were 10 primary sex cells, how many of each type of gamete would be found? If there were 5000, how many of each would there be?

Figure 429 shows that an *RW* plant will form two kinds of gametes: half contain *R*; half contain *W*. If sperm are allowed to fertilize eggs the fertilizations are a matter of chance, since any egg may be fertilized by any sperm. An *R* sperm might meet an *R* egg, producing an *RR* plant. On the other hand, it might meet a *W* egg, producing an *RW* individual. A *W* sperm might meet an *R* egg, producing another *RW* individual; or the *W* sperm might meet the *W* egg, producing a *WW*. All four crossings are possible: namely, *RR*, *RW*, *RW*, *WW*. Since these fertilizations are a matter of chance the first one to occur may be the *WW* one. If because of some accident no more fertilizations were to take place there would be only one offspring, *WW* in this case. But when there are large numbers of fertilizations, a thousand or more, there are, on an average, 25% of *RR* produced, twice as many or 50% *RW*, and 25% *WW*. This is the 1 : 2 : 1 ratio of 25% red-flowered plants, 50% pink, and 25% white. *Exercises 3, 4, 5.*

All this can be stated in this form:

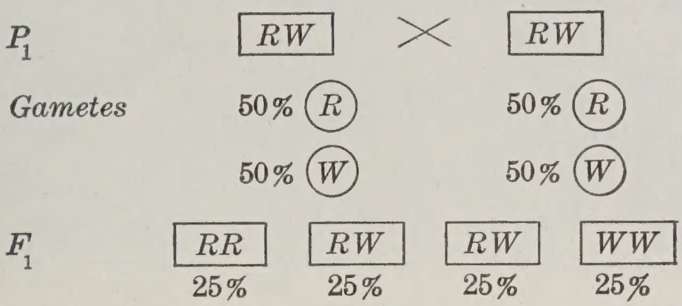


FIG. 430. P_1 means the *first parental generation;* that is, the first mating in this particular experiment. F_1 means the *first filial generation,* the children of the first generation. The next generation would be F_2, the succeeding one F_3, and so on. The × means that matings have occurred.

When two pure forms are crossed. The red-flowered plants with the make-up *RR* are pure. When their primary sex cells go through reduction division the two genes of every pair, of course, separate. One *R* goes into one gamete, the other *R* into the other gamete; but since the genes happen to be the same all the gametes in this case will be alike. This is true of the reduction division in the *WW* plant, also; that is, all the gametes are sure to contain *W*. Therefore when an *RR* plant is crossed with a *WW* plant there is only one kind of fertilization possible and all the offspring will be alike; they must all be *RW* plants. *Exercises 6, 7.*

When contrasting characters do not blend. In the case of the four-o'clock, pink is a blending of the color of the red- and white-flowered parents. But most characters do not blend as do red and white in the four-o'clock or black and white in the Andalusian fowl. Much more frequent is the kind of inheritance shown by guinea pigs. If matings are made between pure black and pure white guinea pigs the offspring are not gray or slate blue. Instead, all the F_1 guinea pigs are as black as the black parent. Whiteness does not show in the animal's coat. Yet the F_1 black guinea pig contains a gene for blackness and one for whiteness. It is a

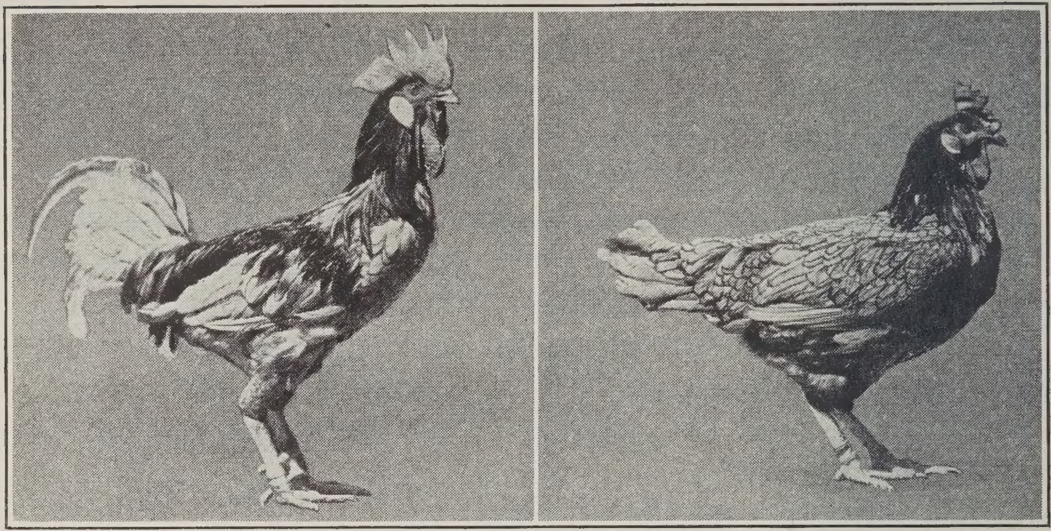


Photo from Snyder's Principles of Heredity

FIG. 431. Blue Andalusian Fowl. These "blue" (slate gray) Andalusian fowl are hybrids containing a gene for blackness of feather and one for whiteness. What color was each parent?

hybrid just as much as the pink-flowered four-o'clock plant. *Exercise 8.*

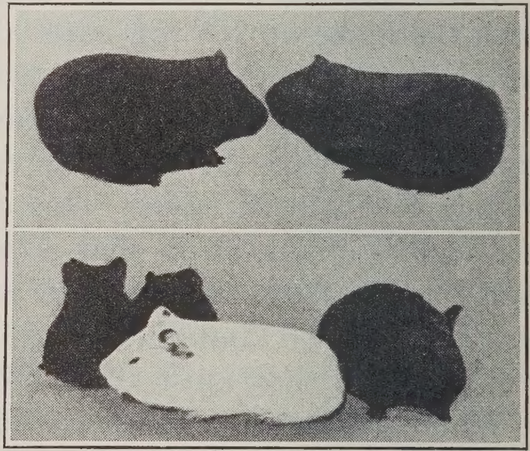


FIG. 432. Are the two black guinea pigs in the upper row pure or hybrid? Would it help you to answer if you were told that the guinea pigs below are some of the offspring produced when they were mated? (*Photographed from Castle's* GENETICS AND EUGENICS *with the permission of Harvard Univ. Press & Prof. Castle.*)

Almost a century ago, Gregor Mendel, an Austrian monk who laid the foundation for this method of studying heredity, became interested in the inheritance of contrasting characters in the garden pea. He crossed tall pea plants with short ones and discovered that only one of the two contrasting characters appeared in the offspring. This happened also with other pairs of contrasting characters that he was studying. So he called the character that appeared in the hybrid *dominant.* And the character that did not appear he called *recessive.* Since blending inheritance did not occur in any of his experiments he arrived at the conclusion that dominance was the rule. He assumed that it occurs in other organisms as well and formulated the "law of dominance." While later work showed that dominance occurs in the majority of cases there are numerous exceptions such as the four-o'clock and the Andalusian fowl. These and some other organisms show *blending inheritance* or *incomplete dominance.* Therefore, biologists no longer speak of a *law* of dominance. *Exercises 9, 10.*

Mendel's experiments with the garden pea. Mendel's experiments are models of clear thinking, accurate observation, and careful recording. He deliberately set out to discover how certain characteristics were inherited in the garden pea, a plant which he raised in large numbers in the monastery garden. He directed his attention to seven pairs of contrasting characters. One pair of contrasting characters was tallness and shortness, the tall plants being six to seven feet high and the short ones less than a foot and a half high. In another case the two varieties used for crossing were different in the color of their seeds, one variety having seeds colored green, the other having seeds colored yellow. Another pair of contrasting characters was smoothness of seed coat and wrinkledness. In each case Mendel permitted the plants to reproduce by self-pollination until he was sure that the plants were pure for the character he was studying. Thus the tall plants when self-pollinated never produced any but tall plants, and so on. Such pure plants when self-pollinated are said to *breed true.* All the offspring show the same character as the parent.

When he had obtained pure tall and pure short plants he began his experiments. He crossed tall plants with short ones. Seeds resulted from these crosses. When the seeds were planted and grew into new plants Mendel studied the F_1 specimens. All the plants were tall, showing that tallness was dominant over shortness. This was an interesting discovery, but of course Mendel did not stop here.

The tall plants of the F_1 were permitted to reproduce by self-pollination and large numbers of the second generation (F_2) were obtained the next season. To Mendel's surprise these F_2 plants were not all tall but showed a 3 : 1 ratio of tallness to shortness. Since Mendel was the first scientist to discover this ratio it is called the Mendelian ratio.

Mendel continued to the next generation (F_3). He permitted the F_2 plants to self-pollinate. In this way he discovered that the short F_2 plants were pure, for they never produced anything but short plants. But the tall plants were of two kinds: some evidently were pure tall for they produced nothing but tall plants; but about twice as many of the tall plants proved to be hybrid.

Similar experiments were performed to study the inheritance of the other pairs of contrasting characters such as seed color and smoothness of seed coat. The results were like those discovered in the crosses between tall and short. In this way Mendel made sure his results were trustworthy. From the study of the F_1 Mendel had formulated his law of dominance. From the study of the F_2 he formulated another law, the law of segregation.

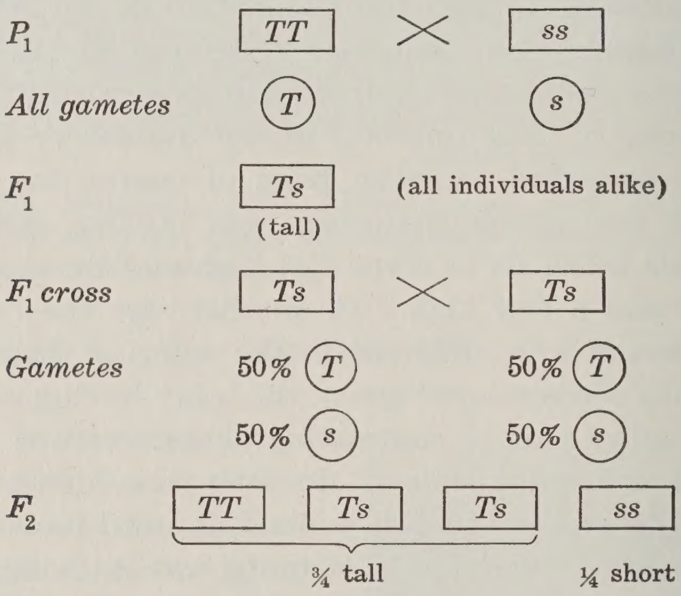
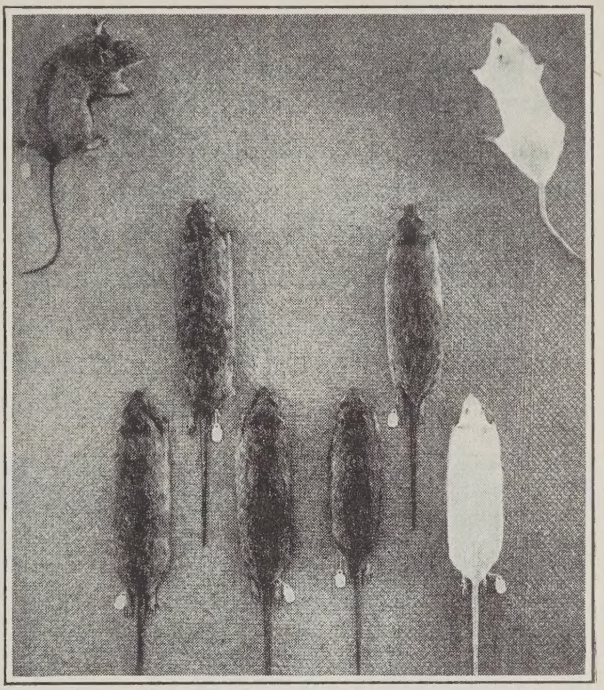


FIG. 433. This is how Mendel's results can be explained. The small letter *s* is used for the gene for shortness because the character is recessive. When Mendel self-pollinated *TT*, *ss*, and *Ts* what were the offspring in each case?

The law of segregation. Mendel's law of segregation states that when hybrids are self-pollinated or crossed the character which had been hidden in the F_1 separates or *segregates* out again in some of the offspring in the F_2. For example, in the case illustrated above, the *ss* appears again in the F_2; that is, shortness is segregated out in the F_2.

Nowadays, since chromosomes have been discovered and matu-



Courtesy Am. Mus. Nat. Hist.

FIG. 434. Stuffed specimens of three generations showing Mendelian inheritance in the rat. Which coat color is dominant?

ration is understood the Mendelian law of segregation is stated in very different words. You know that genes that are brought together in the hybrid do not affect one another. For example, the hybrid four-o'clock has pink flowers; the flowers develop pink petals because a gene for white flowers and a gene for red flowers lie side by side in the nucleus of the zygote. But in spite of their close association the genes are not changed or contaminated, for when this hybrid plant goes through maturation the two genes in every pair separate, or *segregate*. That neither has affected the other is shown by the fact that in the next generation pure white- and pure red-flowered plants appear again. When biologists speak of the Mendelian law of segregation nowadays, they mean that in plants and animals the two members of a pair of genes separate or segregate in reduction division without having changed or contaminated one another. What is true of the four-o'clock is equally true of the guinea pig, of the garden pea, and of other organisms whose heredity has been studied. *Exercise 11*.

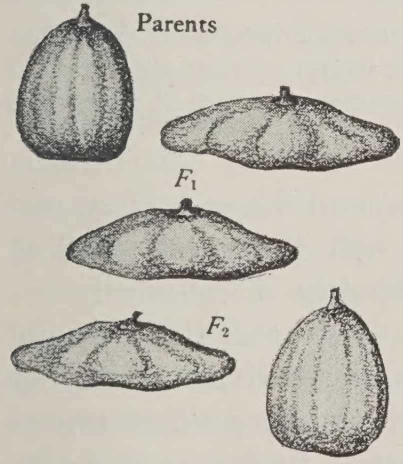
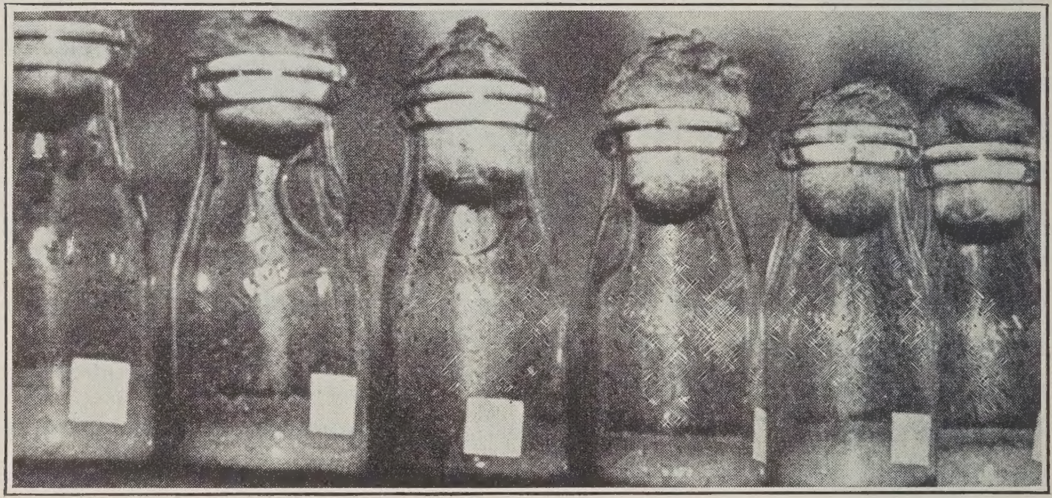


FIG. 435. Shape of fruit is one character that has been studied in squash. Which shape is dominant? Which law explains the offspring in the F_2? Can you show this cross using letters?

More recent experiments showing the law of segregation. The organism in which heredity has been studied most completely is the tiny fly which is so frequently found in the neighborhood of ripe fruit. It is known as the fruit fly or vinegar fly (*Drosophila melanogaster*). It may surprise you that biologists should have devoted so much of their attention to this insignificant insect; but Drosophila is particularly suitable for experiments for a number of reasons. It is small and needs little food. Its life cycle takes only two weeks, so that 25 generations can be followed in one year. The offspring of one mating may number 400, so that large numbers may be studied and counted; this ensures correct ratios. Then, too, it has a relatively small number of chromosomes, only four pairs, each pair differing from the others in size and shape. Many important experiments have been carried on with the fruit fly; all of them have added evidence supporting Mendel's discoveries.



Courtesy Prof. H. Charipper, New York University

FIG. 436. Half pint milk bottles make cheap homes for families of fruit flies. In a laboratory where fruit flies are studied, you would see row after row of such bottles. Each contains flies with some character or group of characters to be followed in experiments.

One of the characters singled out for study was the shape of the wing. If matings are made between flies with normal wings and flies with short (vestigial) wings the long-wingedness proves to be dominant. The F_1 are all long-winged; their gene make-up is *Lv*. When these hybrids go through reduction division the *L* gene and the *v* gene segregate or separate without having contaminated one another. Then when the gametes of one hybrid fertilize the gametes of another hybrid the offspring show the normal ratio. *Exercises 12, 13.*

The number of organisms in which the inheritance of characters has been studied by Mendelian methods is large. Corn, snapdragons, plants of the squash family, the evening primrose, the Jimson weed, and tobacco are among the plants that have been studied extensively. The animals are even more numerous: dogs, cats, rats, mice, cattle, horses, rabbits, certain moths, fowl, the fruit fly, wasps, certain fish, and man himself. In each case the two genes of a pair segregate in the reduction division without having changed one another. The law of segregation holds.

For many hundreds of years before Mendel, breeders of plants and animals had been interested in heredity from the practical point of view. And many biologists had crossed plants with different characters. You may wonder why so little was understood about inheritance at the time Mendel started his work. The reason for this is that breeders failed to concentrate on the inheritance of one character at a time. In their experiments they compared the organism as a whole with its parents and the results became bewildering, as figure 438 illustrates. Mendel's great achievement was that he appreciated the necessity for experi-

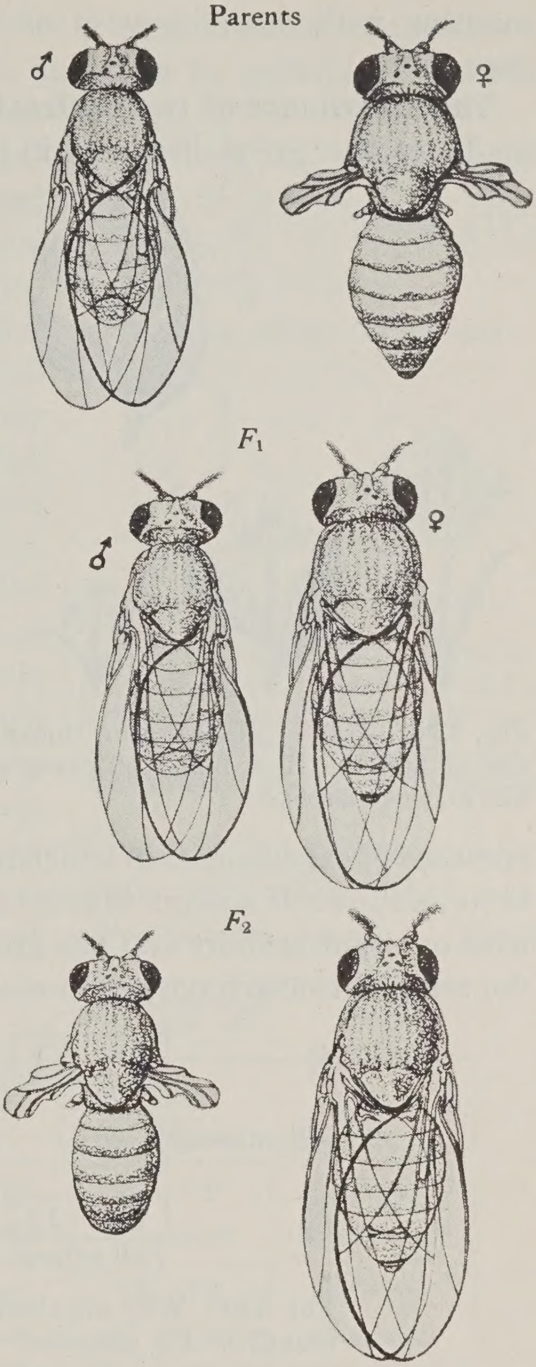


FIG. 437. Diagram of cross between long-winged and vestigial-winged fruit flies. Which character is dominant? How do you know? In what ratio will long and vestigial appear in the F_2 if large numbers of flies are produced?

menting with one character at a time. This was a relatively easy task.

The inheritance of two contrasting pairs of characters. Mendel made another great discovery in the course of his experiments. It grew out of experiments in which he attempted to answer such questions as these: If a plant that is tall and has yellow seeds is crossed with one that is short and has green seeds in later generations will the tall plants also have yellow seeds or may they have green seeds?

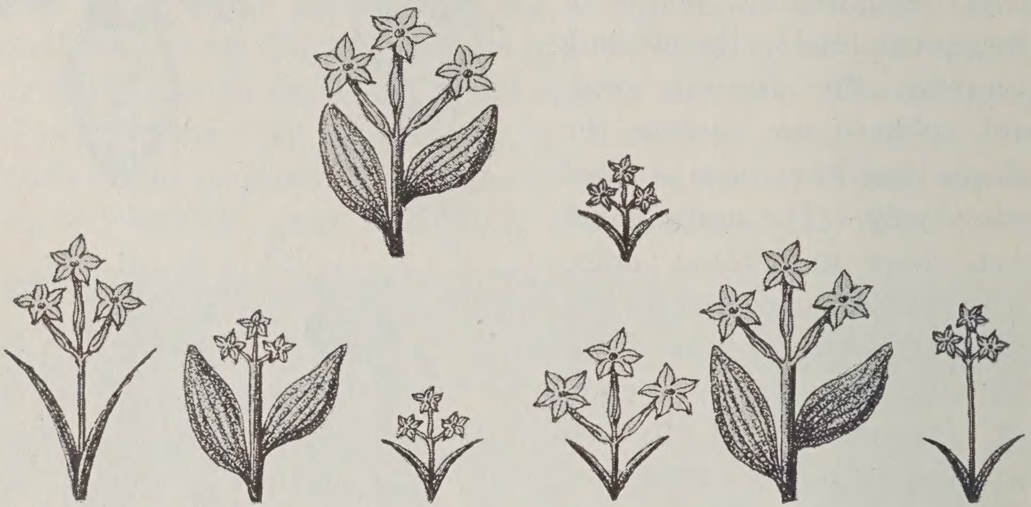


FIG. 438. Note length of stem, thickness of stem, size of leaf, shape of leaf, size of flower. How many offspring are like the parents? How many are like neither parent?

P_1 $\boxed{TT \quad YY} \times \boxed{ss \quad gg}$

All gametes $\textcircled{TY}$ $\textcircled{sg}$

F_1 $\boxed{Ts \quad Yg}$ (all have the same make-up no matter how many offspring)

(tall yellow)

FIG. 439. Why are there not some TT gametes found? or YY gametes?

Mendel began his experiments by crossing plants that were pure for tallness (dominant) and yellow-seededness (dominant) with plants that were pure for shortness (recessive) and green-seededness (recessive). The F_1 plants were all tall and when the time came for them to produce seeds these were all yellow, as shown in the diagram. Of course, these F_1 plants were hybrid with respect to size and hybrid with respect to seed color.

Mendel permitted these *dihybrids* (organisms that are hybrids in two characters) to self-pollinate and then he gathered the seeds. When he planted them the next season he obtained an F_2 with unusual plants. Some were tall and had yellow seeds, others were short with green seeds. These resembled the grandparental plants. But there were also F_2 plants in which the characters were differently combined. Some of these were tall with green seeds; others short with yellow seeds; that is, new combinations were found. Thus Mendel discovered that the combinations of characters found in the parents were broken up; apparently each character had been passed on independently of the other. Later Mendel checked this by crossing plants pure for tallness (dominant) and greenness of seeds (recessive) with others that were pure for shortness (recessive) and yellowness (dominant). Again

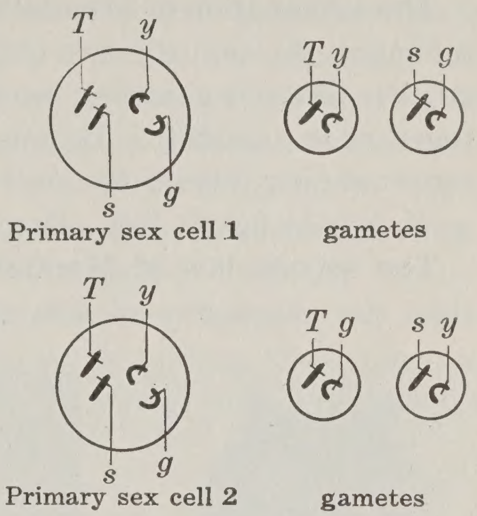


FIG. 440. This diagram shows two primary sex cells of a plant that is hybrid for size and hybrid for seed color. How many different kinds of gametes may a dihybrid produce?

F_1 *cross* $\boxed{Ts\,Yg} \times \boxed{Ts\,Yg}$

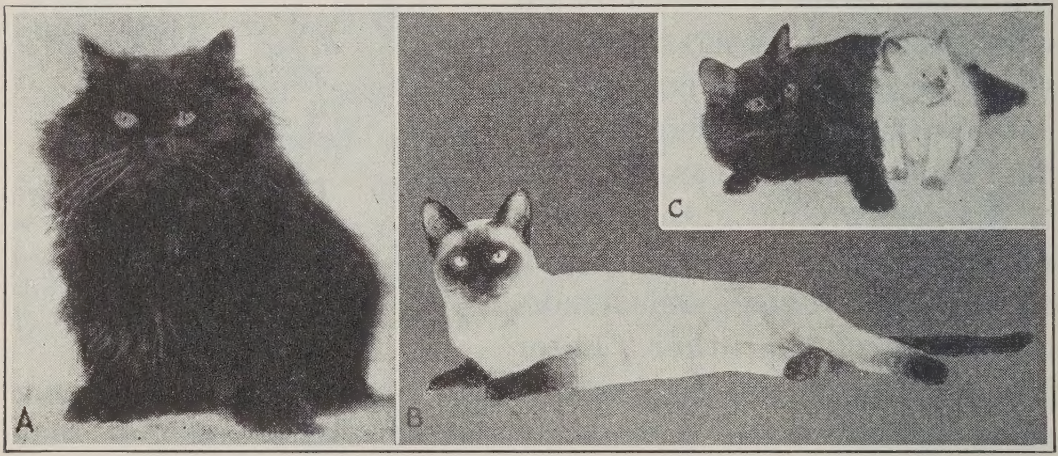
		Male gametes			
		TY	*Tg*	*sY*	*sg*
Female gametes	*TY*	*TT YY* tall yellow	*TT Yg* tall yellow	*Ts YY* tall yellow	*Ts Yg* tall yellow
	Tg	*TT Yg* tall yellow	*TT gg* tall green	*Ts Yg* tall yellow	*Ts gg* tall green
	sY	*Ts YY* tall yellow	*Ts Yg* tall yellow	*ss YY* short yellow	*ss Yg* short yellow
	sg	*Ts Yg* tall yellow	*Ts gg* tall green	*ss Yg* short yellow	*ss gg* short green

FIG. 441. How many of the sixteen crossings result in tall yellow plants? in short yellow? in tall green? in short green? What ratio does this give when you are dealing with large numbers?

the F_2 contained plants in which the grandparental combinations had been broken up.

The explanation of Mendel's results. You will remember that in reduction division the two chromosomes of each pair separate and go into different gametes; no two chromosomes of a pair are found together in a gamete. Because of this, when two pairs of chromosomes are involved there are two possibilities for forming sex cells as shown in figure 440. *Exercises 14, 15.*

The second law of Mendelian inheritance. Mendel discovered that the characters of size and seed color were inherited independently of one another. In later experiments with other combinations of two characters he obtained similar results. Every character was passed on to the offspring independently of every other. Mendel spoke of this as the law of *unit characters.* Mendel knew nothing of chromosomes or genes, nor of their significance for the study of heredity.

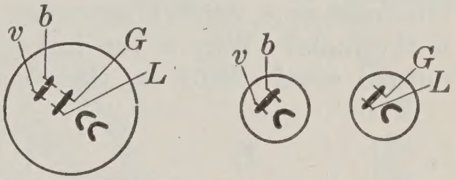


Courtesy Journal of Heredity

FIG. 442. Inheritance of length of hair and coat color. The Persian cat (A) and Siamese cat (B), grandparents, gave rise to the black, long-haired daughter in (C). The light colored kitten is the F_2 generation. What interesting combination of characters shows in the F_2 kitten?

Now since reduction division is understood biologists speak of a *law of independent assortment.* By this they mean that normally each pair of chromosomes goes through reduction division independently of every other pair of chromosomes, as was shown in the diagram. If, therefore, the genes for two characters are in different chromosomes the pair of genes for one character will act independently of the pair of genes for the other character.

Not all pairs of genes are assorted independently of one another. Each pair of chromosomes goes through reduction division independently of every other pair. But of course there are genes for many different kinds of characters in one chromosome. If you happened to study the inheritance of two genes which lie in the same chromosome the results would be different from those Mendel obtained. For example, in the fruit fly the gene for black body lies in the same chromosome as the gene for vestigial wing. When reduction division occurs these two genes normally remain together. They are said to be *linked*, because, lying in the same chromosome, they stay together. In cases such as these the law of independent assortment (Mendel's law of unit characters) does not apply. It so happened that all the characters Mendel chose for his experiments were characters determined by genes which lie in different chromosomes. But since there are genes for many different characters in one pair of chromosomes, there are many cases of linkage. *Exercise 16.*



Primary sex cell gametes formed

FIG. 443. No matter how many of these primary sex cells go through reduction division, the genes *v* and *b* tend to remain together, for they are linked. If *v* were in one of the curved chromosomes, what result would you get? Explain.

Recent advances in the knowledge of genes. In thousands of experiments performed on the fruit fly in the laboratory of Thomas Hunt Morgan and in other laboratories all over the world it has been discovered which characters are linked to one another. In the fruit fly, the results of breeding experiments show that there are four sets of linked characters. The microscope shows four pairs of chromosomes. This is a strong argument for the gene theory.

The evidence that has been gathered, chiefly by the study of Drosophila, indicates that genes must lie in a straight line in the chromosomes. Biologists have gone so far as to assign a place to each gene in the line and have charted chromosome maps to show this arrangement. They have arrived at these conclusions as the result of much experimental evidence too difficult to present here. Chromosome maps have been prepared for several other organisms; the most complete of these is the map for the corn plant. *Exercise 17.*

The great care with which biologists have examined every organ in experiments on heredity has led to the important discovery that a gene affects not only one character but many; in fact, each gene probably affects most if not all the characters of an organism. Although one character is so strongly affected that it is customary to connect the gene with it, other characters are slightly affected too. Because this is true for all genes, biologists now say that every character is determined by every gene; that is, the characters of an organism are the product of the action of all the genes.

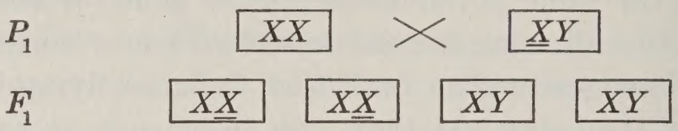


FIG. 444*a*. The line under the *X* indicates that the chromosome carries the gene for color-blindness. The *Y* chromosome carries no gene to hide the color-blindness gene, which is recessive. Which of the parents is the female? Which is the male? Why is the father color-blind? Why do the daughters have normal eyes? Why do the sons have normal eyes?

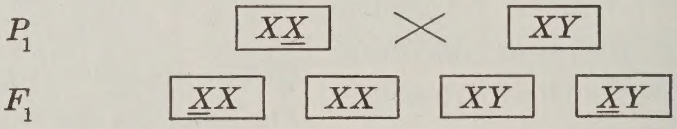
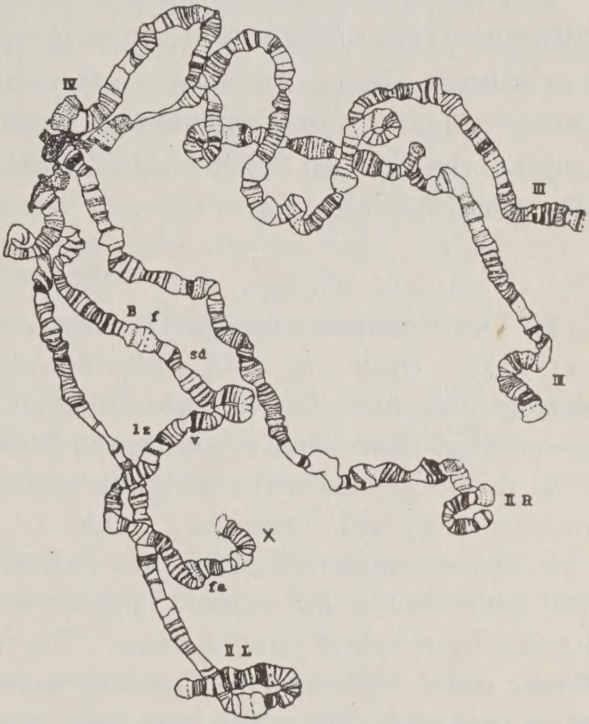


FIG. 444*b*. One of the females of the F_1 is mated with a normal male. On the average how many sons are color-blind?

Sex is inherited like other characters. Early in the study of the chromosome theory of heredity, even before the gene theory had been worked out, it was noticed that the male and female organisms of a species differed in one pair of chromosomes. In many animals the male had one pair that did not look like a pair, for the two were somewhat unlike; the female did not have this. These chromosomes were therefore called *sex chromosomes.* In the human species, which has 24 pairs of chromosomes, the cells in a man have 23 pairs of chromosomes just like those in the cells of a woman. But added to these, a man has a pair of dissimilar ones, called *X* and *Y*, while a woman has a pair of like ones, two *X* chromosomes. Evidently an animal or plant inherits "maleness" or "femaleness" just as much as it inherits any other character.

There are certain characters that are definitely associated with one sex or another. They are said to be *sex-linked.* A type of color-blindness in human beings is one of these; another is hemophilia (the trait of being a "bleeder"). From the way each of these characters is inherited it is known that the gene that determines the character must lie in the sex chromosome. *Exercises 18, 19.*

Individuals of the same species must differ. The study of why parents and offspring resemble and differ from one another is now called *genetics.* Your brief study of genetics has explained several important facts. First, an individual that has two parents is not exactly like either parent. Under laboratory conditions, after long and careful breeding a relatively simple organism like the fruit fly may be made pure in every character. Each sex cell, therefore, will be like every other. But under normal conditions this does not happen; an individual formed by sexual reproduction is not exactly like either parent.



Courtesy Professor T. S. Painter

FIG. 445. A diagram by Professor Painter of the giant chromosomes found in the salivary gland cells of fruit fly larvae. The lines, of course, are *not* genes. The letters mark the location of some genes.

Furthermore, you learned that the offspring does not resemble the two parents equally. In fact, it may have a character possessed by neither parent, nor by any of the grandparents. A recessive gene may be carried for many generations without meeting its mate; it may, therefore, be many generations before it makes itself noticeable in any of the offspring. You would call such an individual a "throw-back."

Genetics explains further why the many offspring of the same parents are all different from one another. When you studied the inheritance of two characters at the same time you saw that there were 9 different genetic make-ups possible in the F_2. If you study three genes which are not linked in one chromosome you get 27 different possible offspring. Four pairs of genes will produce 81 different genetic make-ups. Mathematicians show that in man, with 24 pairs of chromosomes, there are millions of possibilities for different combinations. The likelihood that any two human beings will have the same gene combination is very small. By independent assortment and fertilization new combinations and recombinations are continually occurring.

Individuals of the same species are not the same; they are different from one another, or as it is more often stated, they show variations. Some variations are caused by the fact that in each reduction and fertilization the chromosomes (and genes) assort independently and are brought together in ever new combinations. *Exercises 20, 21.*

Exercises

1. Draw (diagrammatically) a four-o'clock plant with red flowers (use crayons). Draw one with white flowers. Below show what their offspring must have looked like. Imagine that two of these are crossed. Below that show what types of grandchildren might be expected.

2. You have learned that gametes are always pure. Organisms may be pure or hybrid. Account for this.

3. To show the offspring of a hybrid cross. Put 200 red beans and 200 white beans into a jar. Imagine that each bean represents an egg formed by a hybrid pink blossom. The red bean (egg) has a gene for red-flower color. (Do not get the impression that the egg would in reality show redness.) The white bean (egg) carries a gene for whiteness. Why do you have the same number of red and white beans in the jar? Set up another jar like it; in this case imagine that each bean represents a sperm. Shake each jar to mix the beans that are in it. With your eyes closed pick one bean out of each jar and put the two beans together as though the cells were forming a fertilized egg. Keep a record of the kind of zygote you get. Do this again and again until the jars are empty. How many of each kind of offspring did you obtain? What ratio is this?

4. What genes for flower color does a pink-flowered four-o'clock carry? What kind of gametes will it form? What genes does a white-flowered four-o'clock carry? What kinds of gametes will it form? Using R for the red-determining gene and W for the white-determining gene, work out the cross of these two types of plants. What ratio would you get if you used large numbers of plants in a real experiment?

5. A biologist, studying his experimental four-o'clock plants in the greenhouse, discovered that he had 294 with white flowers, 311 with red flowers, and 629 with pink flowers. The parents of these plants had the same gene make-up. What was it? How do you know?

6. If the plants in Exercise 5 are the F_2 of a cross, what were the grandparents (P_1) like? What genes did they carry? How do you know?

7. By using letters can you show the results of crossing Andalusian fowl through the F_2 generation if you start with a pure black and pure white?

8. Show the guinea pig cross through the F_1 generation. Since whiteness is recessive how should you write the letter to represent it?

9. Sorghum is a plant much like corn. If you can obtain seedlings that are the F_2 generation of a cross between red-stemmed and green-stemmed plants find out how many are red-stemmed, how many green-stemmed. Which is dominant? What is the ratio?

10. If purple and white F_2 ears of corn are available count how many kernels there are of each color. What ratio do you find? Which color seems to be dominant over the other? Add together the results obtained by other members of the class. What ratio do you obtain now? Can you explain this?

11. If a biologist were to cross tall garden peas (not permitting self-pollination to take place), what offspring might he obtain? (This is a catch question; study it carefully.) Explain your answer. Can you state the "ratios"?

12. Write the diagram showing the cross between pure long-winged and pure vestigial-winged ($LL \times vv$) fruit flies to the second filial generation.

13. Suppose that you have an organism that is dark in color, where dark color is dominant over white. You wish to find out whether or not this organism is pure dark or hybrid dark. How could you find out by one cross? (Will it help you to know that it is called a *backcross?*)

14. You can demonstrate how chromosomes assort themselves when a primary sex cell having two pairs of genes forms sex cells. Imagine you are dealing with a dihybrid which has genes for red and white in one pair of chromosomes and tall and short in a second pair. Let a red bean represent the chromosome with a gene for redness; a white bean its mate. Cut small squares of paper of the same size and write *T* on one half the number and *s* on the other half. Put the paper and beans into one jar. As this jar "makes" sex cells you must be sure that each sex cell gets one of each pair; that is, a chromosome for color and a chromosome for size. Pick out many "sex cells" without looking. How many chromosomes must there be in each? Keep a record of the kinds of sex cells produced.

15. To test your understanding of reduction division when you are working with two pairs of chromosomes show what possible sex cells may be formed from a primary sex cell with these pairs of characters: black and white, and rough and smooth. Work out reduction division in a *trihybrid, Ts Yg Pw.* Let *P* stand for purple blossom and *w* for white blossom. How many types of gametes are produced?

16. Suppose that genes *Y* and *T* were in the same chromosome, and genes *g* and *s* in its mate. Draw a diagram to show the reduction division.

17. The two chromosomes of a pair may be so twisted in reduction division that when they separate the two have exchanged pieces. This is called *crossing over.* A trihybrid might have genes *abc* in a row in one chromosome and *a'b'c'* in another. After twisting, one chromosome may have *abc'* the other *a'b'c.* What effect has crossing over on the usual ratios?

18. If a mother is carrying a recessive gene for color-blindness and has four children, two of whom are sons, must one son be color-blind? Explain your answer.

19. Show, by diagram, the inheritance of hemophilia.

20. Suppose an individual had only two pairs of chromosomes, *aa* and *bb.* Is it pure or hybrid? It is mated with one like itself, with the make-up *aa* and *bb.* Would the children be like or different from the parents? However, this seldom happens, except in a laboratory. Suppose the one parent were a dihybrid with chromosomes *aa'* and *bb'.* The other parent is *AA'* and *BB'.* Are any of the children exactly like either parent? Explain.

21. *Summary.* There is so much information in this section that you would find it impossible to summarize it unless you used a carefully planned method. To understand genetics you must be sure that you understand mitosis and reduction division. When you are certain that you do, make sure that you understand what is meant by a gene. Explain dominance and incomplete dominance, with examples. Explain the law of segregation in your own words; give examples to show how it works. Can you do this for the law of independent assortment, also? What connection is there between linkage and independent assortment? Go back half a century, in imagination, and explain what Mendel discovered. Explain Professor Morgan's contributions and other recent discoveries about genes. When you have done this, you will know why the transmission of genes must cause differences as well as likenesses between parents and offspring.

Activities for the Junior Biologist

1. There are many interesting breeding experiments that you can carry out. Mice breed quickly and the inheritance of coat color can be studied. Do not attempt experiments before you know how to care for the mice. Cross gray and white mice. If you can obtain them, cross yellow and black mice. Consult your teacher, for some crosses involve complications which you will not be able to explain until you know much more about genetics.

2. The fruit fly is easy to obtain at any supply house and can be bred easily. A Turtox leaflet gives you full instructions for culturing them.

3. The Brooklyn Botanic Garden, Brooklyn, New York, will sell you sorghum and pea plants which show a three to one ratio. You will be interested to discover the characters for yourself.

4. If you have a garden, there are many other experiments you can perform. Find out which flowers self-pollinate. Perform artificial pollination, using all precautions. By self-pollinating for several generations you may establish pure forms. Do you know why? Cross these forms. These experiments would, of course, extend over several seasons.

5. Your school is probably in need of charts and other demonstration material for showing the results of various crosses. Prepare some, using college textbooks as the sources of information.

6. Could you invent some interesting devices for showing the assortment of genes in reduction division or for showing fertilizations? A large board with hooks and wooden or paper objects which can be moved around on the board and rearranged will prove helpful.

7. A group of pupils (representing chromosomes) with a string of genes pinned on each, can move themselves about to explain reduction division in dihybrids. You can also show linkage in this way. Can you plan it?

8. If any of your classmates are also interested you might form a Genetics club to get the benefit of one another's help.

3. Some Differences between Parents and Offspring Are the Result of Changes in Genes and Chromosomes; These Breed True

Recombinations of genes. In the preceding problem you learned that the transmission of genes accounts for differences as well as likenesses between parents and offspring, and that with the reshuffling of genes in every mating new combinations are formed. The organism which is different has merely a new combination of old genes; strictly speaking it has nothing new. When the tall, yellow-seeded garden pea was crossed with the short, green-seeded one, some of the grandchildren were tall and had green seeds. These plants had a new combination of characters but no new characters, for tallness and green-seededness were present in their ancestors. So too the F_2 kitten in the photograph above has merely a new combination of characters, long hair with Siamese marking.

Entirely new characters may appear. From time to time, however, parents produce offspring with a really new character; something that is not the result of the normal recombination of genes. Such a case occurred in 1910 in the fruit fly, when a student in a biological laboratory found a fly in one of his cultures that had white eyes instead of the normal red. As far as anyone knew this was the first white-eyed Drosophila that any biologist had seen. When the fly was crossed with a normal red-eyed fly the F_1 were red-eyed; but in the F_2 some flies had white eyes. Thus it was discovered that this character was inherited; it was a new character.

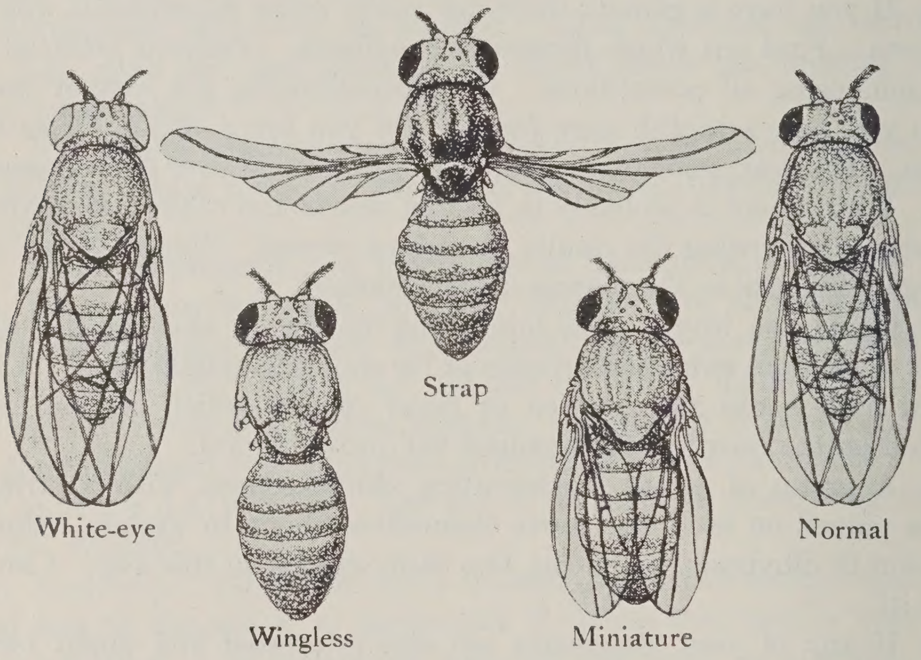


FIG. 446. The fruit fly on the right is normal. The others show four inheritable changes that have occurred. What are they? What do the words *strap* and *miniature* refer to? What other wing character have you read about?

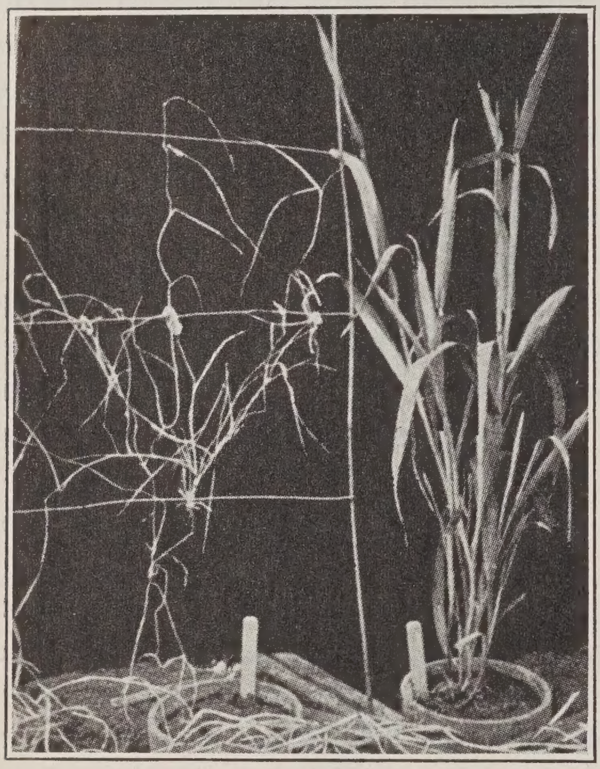
This was the first of about five hundred changes in characters that have appeared in the fruit fly. In spite of this apparently large number, you must not think that such changes occur frequently. Apparently they take place somewhat more often in the fruit fly and biologists have studied millions of fruit flies. It has been estimated that in about 1 out of 50,000 flies there occurs some change which is visible as a new character. Since an organism's characters are determined by the chromosomes you can see that a new character that is inherited must be caused by a change in the chromosomes. Such changes in the chromosomes are of different kinds.

Changes in the gene. The simplest possible change in a chromosome is a change in a single gene. What happens to a gene when it changes is not understood. This is not astonishing, since no one knows the chemical make-up of a gene. But the change is sudden and complete. Such a change in a gene is now called by the name *mutation* (mew-tay′shun). The mutation (gene change) may produce a large change, or a small one. That is, the new character which the biologist observes may be readily noticeable or scarcely visible. However small the difference, if the new character is inherited and follows the Mendelian rules of segregation it is clear that it was produced by a gene not present before in the organism.

When a single gene mutates the other member of the pair is not changed. The organism is then a hybrid for this pair of genes. In most cases the new gene is recessive to the unchanged gene; in some cases it is dominant. Of course, when the new gene is recessive there is no outward sign of the change until a later generation when two such new genes may come together. Changes in genes may produce harmful effects in the organism. Most mutations do. Vestigial wing is clearly harmful to Drosophila; most of the other mutations shorten the life of the fly. By far the greater number of mutations are so harmful that the organism dies; others merely weaken the animal or plant; a few are an advantage to the organism. Mutations have been seen in many organisms; corn, rabbits, mice, man, and many others. Any organism that shows the result of a mutation is called a *mutant*. *Exercises 1, 2.*

How mutations have been made to occur artificially. A little more than ten years ago Professor Hermann J. Muller, an American biologist, succeeded in producing mutations in the fruit fly, Drosophila, by the use of powerful X rays. To prove that the X rays caused genes to change, Muller counted the number of mutations that occurred among flies that had been X-rayed and among flies that had not been exposed. He found that far more mutations occurred in the flies that had been X-rayed and therefore concluded that the X ray produces mutations. Similar experiments have been performed with plants by other biologists and all of this work has been repeated many times. In all these experiments variations appeared that evidently were changes in the genes of the germplasm, for they bred true and gave the proper Mendelian ratios.

In the case of the fruit fly, many mutations were described over the long period of years in which the flies were so carefully bred and studied by Morgan and his co-workers. It is interesting to note that the mutants produced by Muller's X rays were like those already known. Occasionally these mutants go through another mutation which changes them back to the original type. This happens to mutations that occur without treatment of the fly as well as to those produced by X rays. *Exercise 3.*



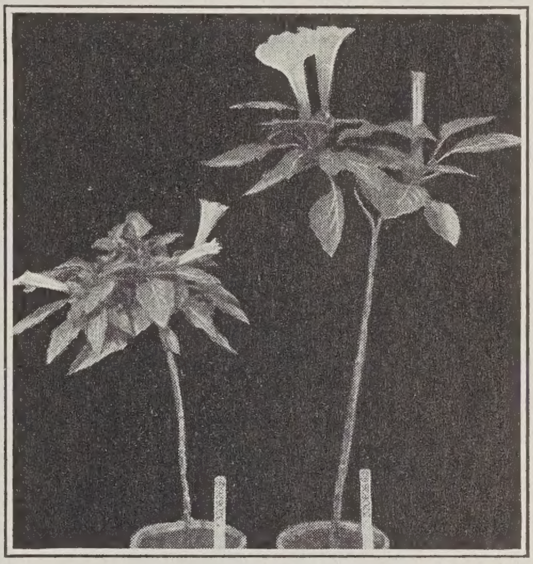
From Snyder's Principles of Heredity

FIG. 447. Mutation in barley produced by X-ray treatment. It is called "vine." How does it differ from the normal plant at the right?

Changes in the numbers of chromosomes. Biologists have examined the chromosomes of the organisms in which new characters appeared. Sometimes they have discovered that the plant or animal in which the new character appeared did not have the normal chromosome number. Sometimes the plant or animal had half the number (haploid), more often it had one whole set of chromosomes beyond the normal number. Some organisms had two extra sets; others even more. These irregularities might well arise during mitosis or maturation. Normally a plant or animal has two genes that affect some character especially. If instead of two genes there are three or four genes, or only one, the character is changed. Recently, such changes in chromosome number have been produced by chemical means. Colchicine, a plant poison, was used. The number of chromosomes was doubled. *Exercise 4.*

Other chromosome changes. Sometimes a piece of a chromosome breaks off and attaches itself to another chromosome. When the reduction division takes place in a cell in which this has happened two types of gametes are produced; one type of gamete gets the chromosome with the added piece and will have two genes for some characters; the other will have the short chromosome with the piece missing and will lack certain genes. When these abnormal gametes are fertilized by normal ones, the zygotes that are produced may have three of some genes or only one. This gives rise to new characters that are inherited by the offspring.

In other cases a piece of chromosome seems to have twisted about end to end within the chromosome so that the order of the genes has been changed. This, too, leads to changes in characters and is, therefore, a cause of differences between parents and offspring.

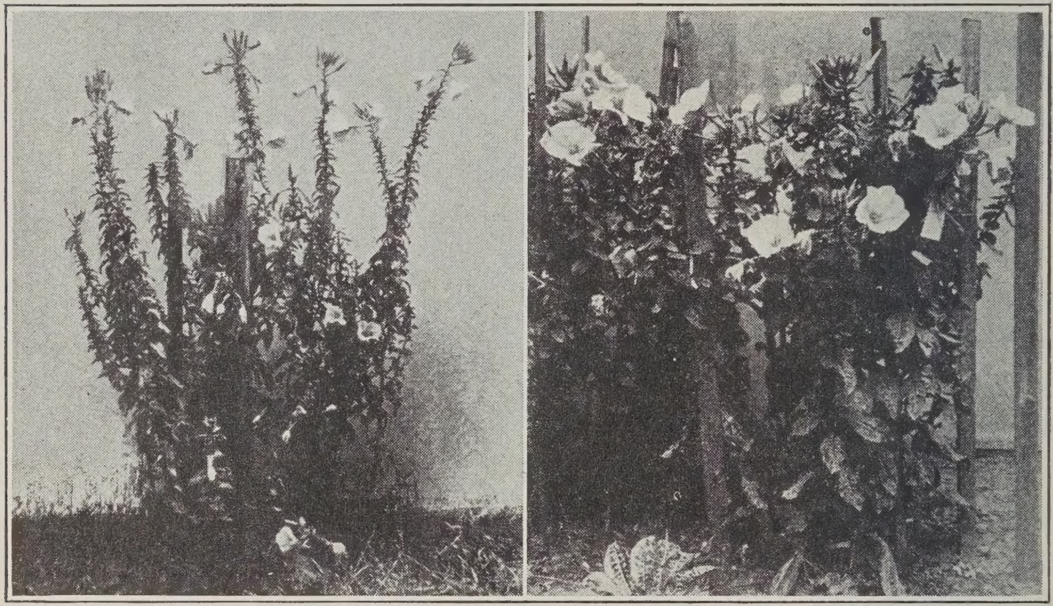


Courtesy Am. Genetics Assn.

FIG. 448. The Jimson weed (Datura) on the left has the half (haploid) number of chromosomes in its cells; the one on the right has the normal (diploid) number. What differences do you note besides height of plant? (*Photo A. F. Blakeslee.*)

De Vries and mutations. The term mutation was first introduced into biology about 1901 by a Dutch botanist, Hugo de Vries, as a result of his experiments with the evening primrose (*Oenothera Lamarckiana*). De Vries had observed new varieties in the field, so he cultivated the plant in his experimental garden. By controlling the matings and keeping careful notes he was able to show that new types appeared and that some of the new types bred true; that is, produced offspring like themselves instead of like the original evening primrose. Among his plants appeared some with red-veined leaves, some with broader leaves, some that were dwarfed, and some that were giants. Some of the changes were striking, others were scarcely noticeable; but they bred true.

These experiments followed after Weismann's statement of the continuity of the germplasm. De Vries, who accepted Weismann's theory, said that changes took place in the germplasm and that these changes were inherited. The word mutation, as used by De Vries, originally meant any change in the germplasm which bred true (was passed on in the same form to the offspring). Recently, however, the term mutation has been reserved for gene changes only. The term *chromosome changes* is used for all other changes in chromosomes that show themselves in new characters and breed true. *Exercise 5.*



Photos by Prof. B. M. Davis

FIG. 449. The evening primrose (left) and one of its mutants (*gigas* or giant). In which respects is the mutant a giant? In which other characters does it differ from the normal parent plant?

Why gene and chromosome changes may produce widely different characters. You know that in many cases a character is the result not of one gene but of several or many genes working together and that, furthermore, one gene has an effect on many characters. Since this is the case you can readily see that a very slight gene change might produce most unexpected results. The gene for white eye in Drosophila (a mutation) not only produces white eyes instead of the normal red but also makes slight changes in the other characters of the fly. Changes in parts of chromosomes or in single chromosomes or in sets of chromosomes would, therefore, produce even more marked changes. The offspring may then be very different from their parents. *Exercise 6.*

Exercises

1. Assume that whiteness appears as a mutation in a species of dark animals. If the gene that causes the whiteness is a recessive how did the first animal in which the gene changed look? What must be the genetic make-up of the animal that looks white? Suppose that only one such animal appeared. What would have to be done to obtain more of the white animals? Use letters to illustrate.

2. Suppose a changed gene were dominant to the normal. Hornlessness appeared as a dominant mutation in a breed of cattle. Show by letters what must be done to get a pure breed of hornless cattle.

3. Explain fully of what importance Muller's discovery was.

4. Draw diagrammatically the normal mitosis which occurs (after reduction division from 4 to 2) to make a gamete which has 2 chromosomes. Then show by means of a series of diagrams what might happen to produce a gamete which has twice as many chromosomes as it should normally have.

5. De Vries gave the name mutation to a variation which can be inherited. What has been learned about mutations since De Vries's discovery (1901)?

6. *Summary.* You will find it easy to make this summary. Read the paragraph titles carefully. What is the one main topic under which the others will fit as subtopics? Write your outline and fit in the few necessary facts briefly. The last paragraph, though short, is extremely important and might well stand as a second main topic.

Activities for the Junior Biologist

1. Consult some textbook in genetics to discover how many of the mutations that have appeared in Drosophila are dominant, how many are recessive. How many are unfavorable to the species?

2. Jaffe's *Outposts of Science* will give you some interesting information about Morgan and Muller.

3. Demonstrate to the class the various types of chromosomal changes by using plasticine of various colors.

4. What kinds of mutations have taken place in corn, in the soybean, or in other cultivated plants? Prepare a report for the class. (The *Yearbook of Agriculture*, 1936, 1937, will supply information.)

4. Some Differences among Individuals of the Same Species Are Caused by the Environment

Variations due to genetic make-up. The most striking variations within a species are those caused by mutations and chromosomal changes. But these changes are not of frequent occurrence; they are not part of the regular machinery by which sex cells are formed, fertilization takes place, and the zygote develops.

Much more common are the variations produced by the normal processes of sexual reproduction. Since different genes are brought together by fertilization, there are recombinations of genes which cause endless variation among the individuals of the same species.

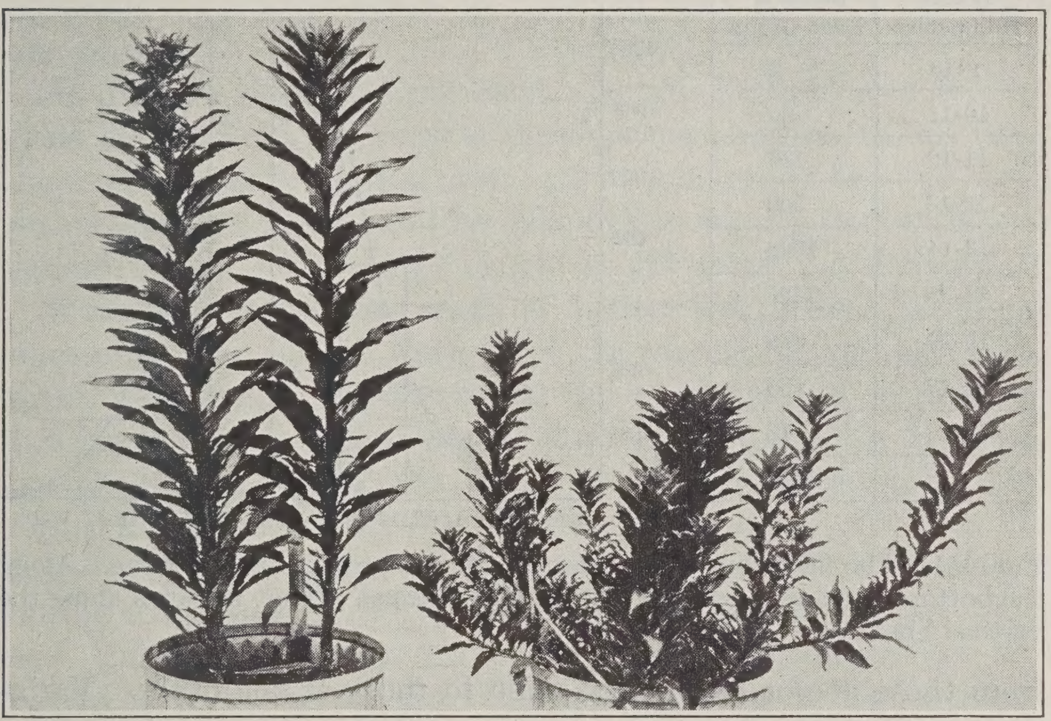
Another type of variation. Everyone knows that children are affected by their food. Children are affected also by the amount of exercise and sleep they get, the kind of air they breathe, and so on. Food, air, sunshine, and playgrounds are factors of the environment which cause changes in you.

But there are many other factors in your environment. Insects, diseases, clothes, cosmetics, radios, theaters, books, school, friends, and family are some of the many others. Just as disease germs may bring about changes in your blood or other tissues, as cosmetics and sunlight may change parts of your skin, as practicing the violin may cause changes among your nerve cells, so every other factor in the environment may produce a change in some of the tissues and organs of your body. Even the slightest change in the environment causes a difference in the individual.

Human beings are not the only organisms that are changed by the environment and therefore show differences among themselves. Every plant is affected by the soil it lives in, by the amount of water it gets, by the amount of light, the force of the wind, by the temperature, and by the kinds of living things that surround it. Every animal is changed by the many factors of its environment, also. *Exercises 1, 2.*

What was shown by a careful measurement of variations. Biologists have long been accustomed to variation within a species.

Upon close examination no two dandelions proved to be exactly alike; no two black bears; no two grasshoppers. Many years ago a scientist made a very careful study of variations in man. He recorded the chest measurements and heights of the soldiers in a Scottish regiment. As you would expect, he found a wide range from the short men to the very tall men, from those with a narrow chest to those with a broad chest. That does not surprise you for you know that these men were different in their genetic make-up and in their environment.



Courtesy Journal Agric. Research

FIG. 450. Two normal plants of the common evening primrose (*O. biennis*) are shown on the left. The single plant on the right received fewer hours (only 10) of daylight each day. What effects did this have on the plant? Why can you not draw conclusions from this picture about the effect of light on plants? What other information would you need?

Since that time there have been many similar studies. In each, scientists have measured a single character and listed the measurements so that the variations in this character could be shown in a table. The length of pine needles and the ability of school children to answer certain types of questions have been among the characters studied. The results of a study made on the length of beans by the Swedish biologist, Johannsen, are shown in Figure 451.

It is often easier, when studying a table like this one, to draw a diagram of it. The diagram is called a *graph.* It shows all the information given in the table in a way that is easy to see.

The measurements of the soldiers, or of any of the other variations referred to above, can be arranged in a curve. When enough individuals are measured there is a very gradual change from those at one end of the scale to those at the other. Variations caused by the environment regularly arrange themselves this way. *Exercises 3, 4, 5.*

Length of Beans Millimeters	Number of Beans in Each Group
9-10	2
10-11	20
11-12	136
12-13	540
13-14	1068
14-15	1125
15-16	636
16-17	180
17-18	18
	3725

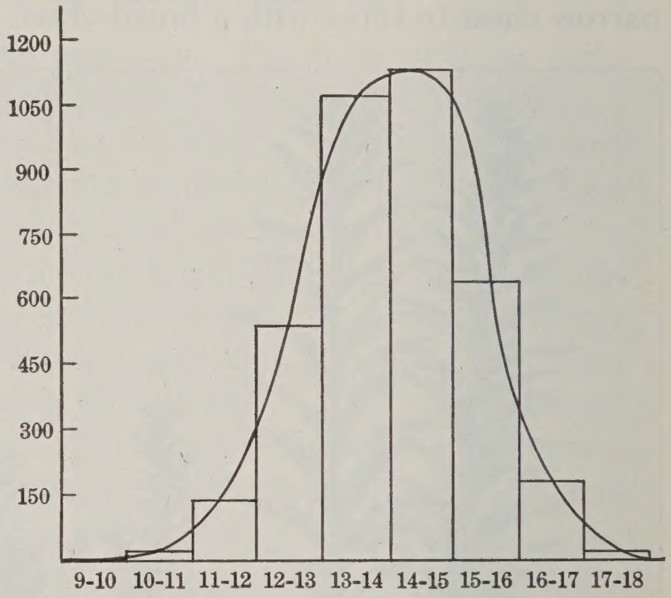


FIG. 451. The figures in the table are built up into a graph or curve. Along the bottom line are shown the lengths of the beans. What is shown along the vertical line?

What Lamarck thought about variations. About the year 1800, Jean Baptiste Lamarck, a French biologist, devoted much time to the study and classification of living things. In this work he observed endless variations in animals and plants of the same species. He saw too that the environment caused changes in organisms. Thus the person constantly exposed to strong sunlight acquires a darker skin. Lamarck saw that frequently, as an animal used some part or organ, it developed; when the part or organ was allowed to fall into disuse it became smaller. You have seen instances of this many times. The muscles of the bookkeeper are usually smaller than those of the steel worker. Lamarck was convinced, as you are today, that the environment causes changes in animals and plants.

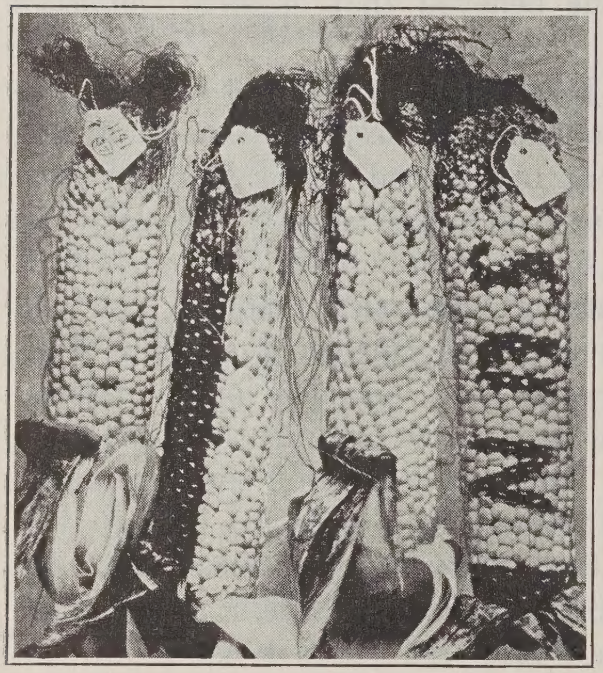
But Lamarck made a further statement: that a variation of this kind would be passed on to the offspring, even if only to a slight degree. Of course, Lamarck did not mean that the whole change would be passed on. But he did believe that if an organ had been used in the parents it would be slightly better developed in the offspring; and that if the organ or part had grown less efficient because of disuse, it would be slightly less well developed in the offspring. In other words he believed that *acquired characters* are inherited.

At the time that Lamarck lived scientists had not seen the nucleus, they did not yet know of chromosomes, mitosis had not been observed, maturation was not understood, genes had not been dreamed of. It was natural for Lamarck to assume that variations caused by the environment should be inherited. *Exercises 6, 7.*

Weismann tested the truth of Lamarck's theory. You will remember that toward the end of the nineteenth century Weismann formulated his theory of the continuity of germplasm. Barring accident, germplasm goes on in an unbroken line from one generation to the next. In each generation the germplasm forms a house or body or "soma" about itself. Within this house or soma the germ cells live. The soma may become changed during the lifetime of the animal or plant; that is, it may acquire new characteristics, but these acquired characteristics are not passed on to the germ cells. Weismann arrived at his conclusion as the result of a famous experiment in which he cut off the tails of white mice for almost twenty generations. As each generation grew to maturity he measured the tails of the mice before cutting them off. He found that the tails neither disappeared nor grew shorter. From this he concluded that the environment changed the soma or body but that the germ cells are not affected by changes in the body. In other words, acquired characteristics (somatic changes) are not inherited.

There has been much criticism of Weismann's experiment. It has been pointed out that cutting tails produced such a crude acquired character that no change need have been expected. No one believed that if a man lost his leg in an accident his child born later would have a shorter or a weaker leg. Scientists wanted more evidence on the question of inheritance of acquired characters. *Exercise 8.*

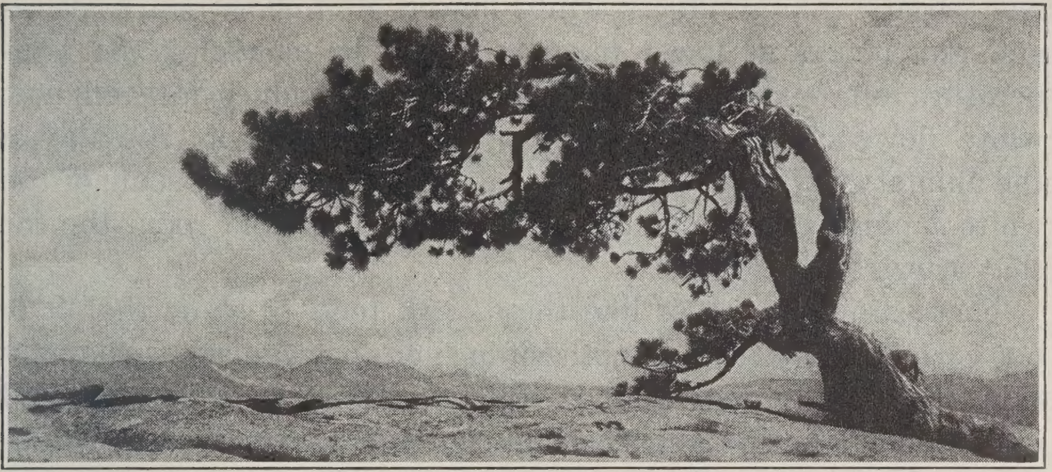
More convincing experiments were performed. As a result of the criticism of Weismann's experiment other biologists have performed experiments of many kinds on many animals and plants to find out whether acquired characters can be inherited. In all cases the results have been the same: acquired characters are not inherited. A most interesting experiment was performed by two American scientists. They removed the ovaries from a pure black guinea pig and placed them in the body of a white guinea pig. When mated with a white male (*ww*) this white guinea pig produced nothing but black offspring. The ovaries that had been transplanted into the female contained genes for black fur. Evidently these genes in the eggs within the ovary were in no way affected by the body of the white animal. *Exercise 9.*



Courtesy Brooklyn Botanic Garden

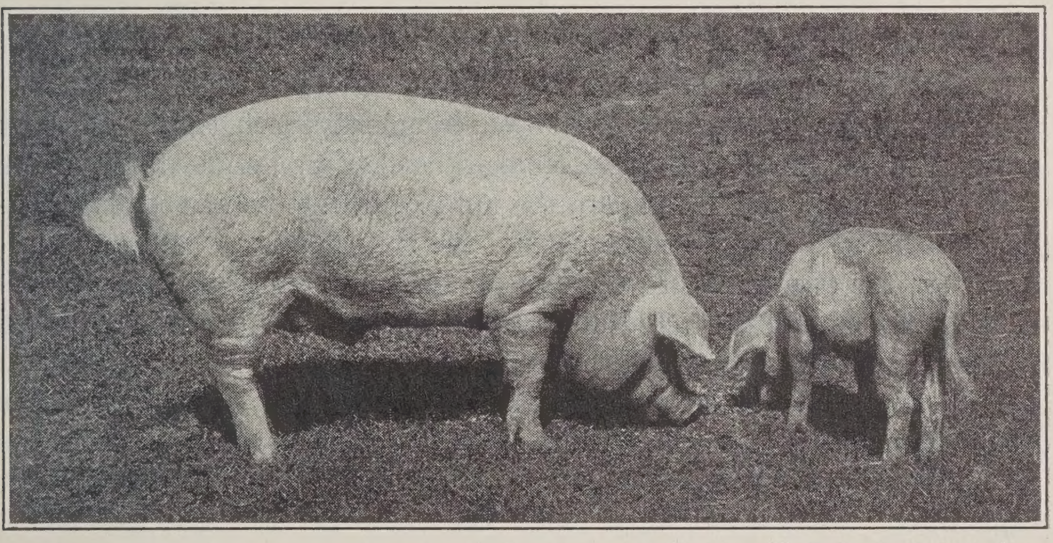
FIG. 452. This corn contains genes for the production of red-colored kernels. But the genes can produce red kernels only when light reaches them. Professor R. A. Emerson cut away part of the husks in the second and fourth ears. How did the word SUN appear?

The characters of the individual depend on the environment and genetic make-up combined. Even though environmental changes cannot be inherited you must not overlook the importance of the environment in determining what an individual will be like. The effects of the environment are even more far-reaching than you would at first expect. Although a gene is necessary to determine a certain character, in many cases a gene fails to produce a given character unless particular conditions of the environment are present. For instance, it is well known that in some fruit flies there is a gene for vestigial (shortened) wing. But the size of the vestigial wing is determined not only by a gene but by the temperature of the fly's surroundings. If the temperature is



Courtesy U. S. Dept. of Interior

FIG. 453. Sentinel Pine, Yosemite National Park. Why is it not straight with outspreading branches on all sides? If its seeds were planted in a sheltered valley how would the trees look?



Courtesy U. S. Dept. of Agriculture

FIG. 454. These hogs are of the same age. The one on the left was raised on clean ground; the one on the right was raised on worm-infested ground. Of what importance is the environment?

raised (the fly grown in an incubator) the wing is found to be larger in the adult. At high temperatures, near the highest that the fly can endure, the vestigial wing is nearly as long as the wing of a normal fly.

Temperature seems to make a difference in the characters produced by genes in various organisms. In the Chinese primrose there are red- and white-flowered varieties. But there is also one variety that produces white flowers at higher temperatures and red flowers at lower temperatures. By changing the temperature for a given plant it may be made to produce now red, now white flowers. In the variety of rabbit known as Himalayan the animal grows white fur at a high temperature. If some of the white is plucked out and the animal kept in a cold room the fur that grows back is black.

There are other cases like these. All tend to show that it is not correct to speak of the inheritance of an organism as the only thing that determines what it will be. What is really inherited is the tendency to produce certain characters under certain conditions. If these conditions are changed different characters are produced. It is both the heredity of the individual and the environment in which it lives that act together to produce its characters. This is an idea of great importance. *Exercises 10, 11.*

Exercises

1. Name the factors of a child's environment which would affect it during the first year of its life. Name other factors besides those in the text which affect you. Compare the number of factors in your environment with those in the environment of the young child; of a dog.

2. Try the effect of more hours of daylight on young bean plants.

3. Study carefully a handful of bean or sunflower seeds and list all the small characters in which they vary.

4. Study the variation among members of your class in regard to some easily measured character, such as height. Draw a curve to show the results of your measurements. If this differs from the curve in the text, explain.

5. Can you suggest a character in some plant or animal (of which you can obtain large numbers) which might be measured to see whether the curve is like the one obtained by Johannsen?

6. You may have heard that a man who spent much time during his youth developing the muscles of his body had a child who was particularly good at athletics. How can you explain this? Can you use this case as evidence to support any theory? Why or why not?

7. Ask your parents or other adults for examples of what they consider cases of the inheritance of acquired characters. Discuss these carefully in class. Is evidence presented in any of these cases?

8. Name all respects in which Weismann's experiment was unsatisfactory.

9. What would be the control in the experiment in which guinea pigs' ovaries were transplanted?

10. *Summary.* This section is so short that the title actually gives you a summary. State it in your own words. What evidence can you give to support your statements? The work of several biologists is explained. Are you sure that you know what each contributed?

11. *Unit Summary.* How would you explain briefly that the organism must resemble its parents and grandparents? (Section 1.) Then turn to Section 2 and show how differences between parent and offspring are caused by (*a*) the fact that the organism normally has two parents, (*b*) the fact that in maturation there is independent assortment of chromosomes. Section 3 explains unusual occurrences which cause variations. Can you name and explain them? In Section 4 a very different kind of variation is described. How does it differ from the first kind? Can you now explain briefly how the organism is the product of its heredity and environment combined?

Activities for the Junior Biologist

1. You could make a much more complete study of variation in height by obtaining figures not only of the members of your class but of the whole school. It would be interesting to see how this curve compares with the class curve.

2. An interesting study is the variation in lung capacity of the members of your class. Construct a spirometer. If possible, gather facts from each classmate about the extent to which he engages in athletics. Does there seem to be any relation between athletic activity and great chest expansion? It would be interesting to find out about the parents of pupils who have the largest chest expansion. Can you draw definite conclusions? Why or why not?

3. Buy pea seeds that are pure for a certain character. Raise them in different environments to see to what extent you can change their appearance. Your results will be of no value unless you keep accurate notes.

4. Read up on Lamarck (*Green Laurels*, by D. C. Peattie or elsewhere).

5. By using an animal that breeds rapidly (Drosophila) you could perform an experiment on the inheritance of an acquired character. How could it be done?

6. Report to the class on the work of Kammerer who during the second decade of this century believed that he had proved the inheritance of acquired characters.

7. Collect examples of different types of variation observed by you or your classmates in various organisms.

Good Books to Read

Castle, W. E., *Genetics and Eugenics.* Harvard Univ.
Conklin, E. G., *Heredity and Environment.* Princeton Univ.
Davenport, C. B., *How We Came by Our Bodies.* Holt.
Dunn, L. C., *Heredity and Variation.* University Society.
Fasten, N., *Principles of Genetics and Eugenics.* Ginn.
Guyer, M. F., *Being Well-born.* Bobbs-Merrill.
Iltis, H., *Life of Mendel.* Norton.
Jennings, H. S., *Biological Basis of Human Nature. Genetics.* Norton.
Mendel, G., *Experiments on Plant Hybridization.* Harvard Univ. (trans.).
Sinnott, E. W. and Dunn, L. C., *Principles of Genetics.* McGraw-Hill.
Snyder, L. H., *Principles of Heredity.* Heath.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.
Whitney, L. F., *How to Breed Dogs.* Judd.

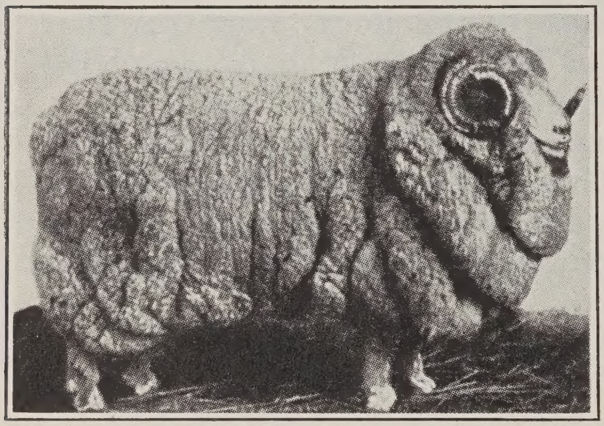
UNIT XIV. THE ACCUMULATION OF SMALL CHANGES IN ORGANISMS THROUGHOUT THE AGES HAS PRODUCED THE MANY TYPES OF TODAY

1. Small Changes in Types of Living Things Can Be Produced by Man's Efforts
2. The Sequence of Fossils in the Rocks Indicates That the Various Types of Plants and Animals Originated from Different Types That Preceded Them
3. Scientists Have Developed Theories to Explain How New Types May Develop from Preceding Types
4. An Understanding of the Origin of Species Has Made It Possible to Explain Many Puzzling Biological Facts

1. Small Changes in Types of Living Things Can Be Produced by Man's Efforts

Varieties and species. When the red eye of Drosophila changes to white by mutation this new character can be inherited and a small change in the type of Drosophila occurs. Although the organism can at once be recognized as differing from the original form it is still a member of the same species because the change is a minor one. It is said to belong to a new *variety*. In many cases it would be impossible for you to determine whether two organisms that differ are sufficiently different to be considered separate species or merely separate varieties within the same species. It is difficult for biologists to draw the line and they do not always agree but, in general, they use reproductive ability as a test. If two organisms which are seemingly different can be mated with one another and produce offspring that can live and reproduce and cross with the parent organism, they can be classified as belonging to two varieties within the same species. If they do not readily interbreed they are different enough to belong to separate species. There are many exceptions, however.

Of what special interest are the changes made by man? Long before history was written man had domesticated animals and cultivated certain plants. In all those years and more particularly in recent years he has produced new varieties of living things. He has bred countless new forms, but most of the changes have been small. Man has been interested in breeding plants and animals better suited to his needs. Throughout this first section, therefore, your attention will be directed toward man's needs and how they have been met by improving plant and animal forms; but as you read you will notice that new varieties of organisms are constantly arising. *Exercise 1.*

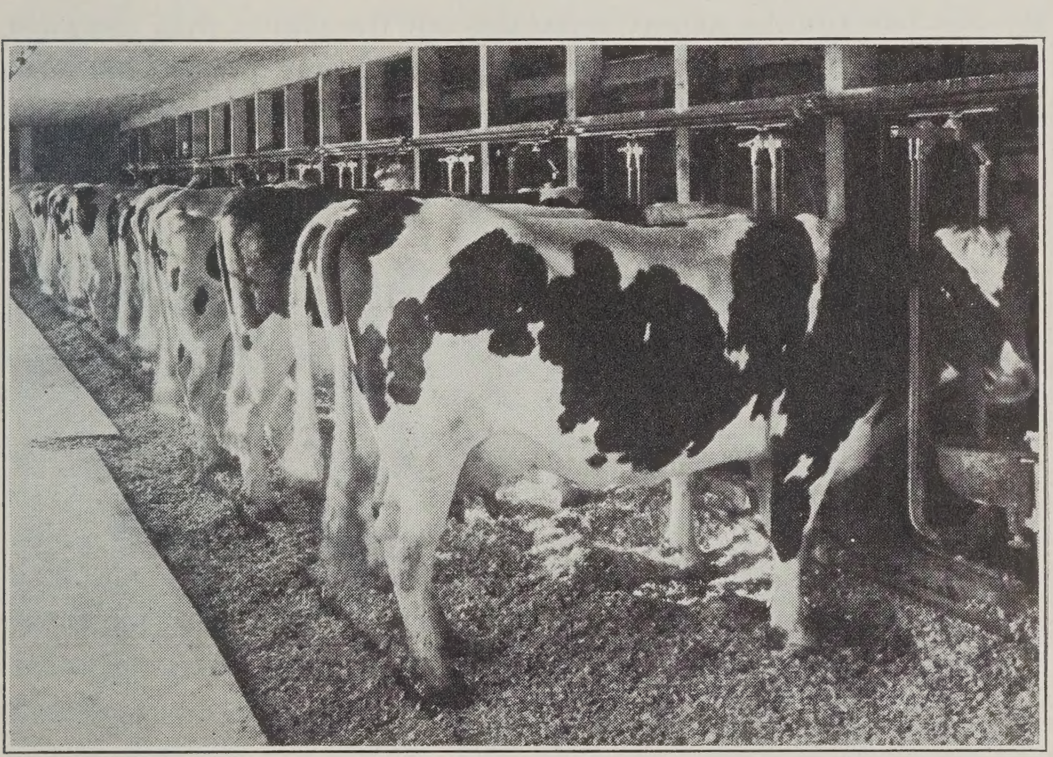


Courtesy Journal of Heredity

FIG. 455. This Merino sheep sold for $13,425. Why did it bring so high a price?

Improving the environment. The modern farmer houses his cattle in barns that are light and clean; he knows that sunshine is as necessary to his animals as to himself. He feeds them scientifically and inoculates them against diseases. Thus he raises cattle that grow to a larger size than ever before and produce more milk. He grows his crops in fields that have been carefully tilled and he fights the insects and fungi that attack his plants. Because of this the yield per acre of wheat, of corn, and of other food plants is far greater than it was. By improving the environment man has improved his domesticated animals and plants. But these characteristics which are acquired because of better environment are not passed on to the offspring. Therefore, improving the environment is not a way of producing new varieties of animals or plants. Other steps must be taken to obtain new types of organisms.

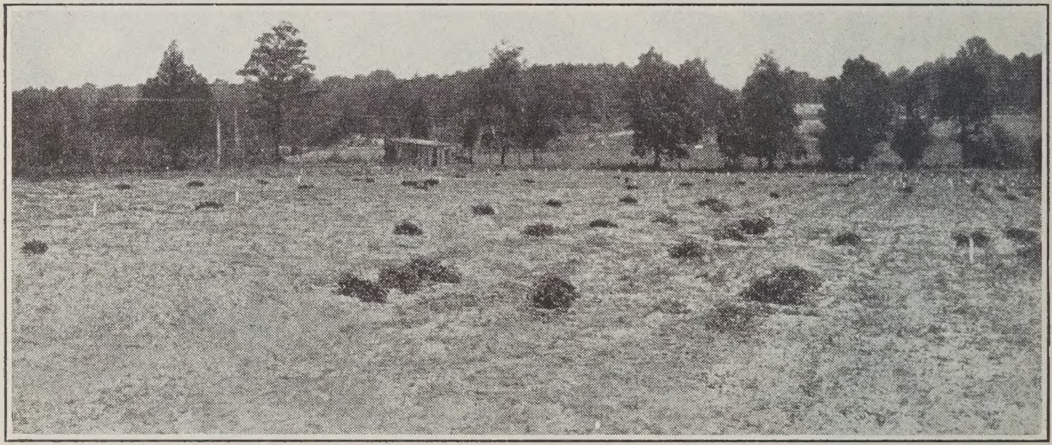
Careful selection produces better types. An interesting example of improving a plant by selection is offered by the soybean. The soybean was perhaps one of the first crops grown by man; it was one of the five food plants sacred to the Chinese, and is still one of the chief crops in the Far East. Some years ago the Department of Agriculture became interested in raising it in this country on a large scale, because of its great usefulness. The whole plant whether dried as hay or when fresh in the pasture makes good feed for animals. The bean seeds yield a large amount of oil which may be used as food or for a dozen different commercial processes; when ground into meal the seeds can be used as food and fertilizer.



Courtesy Cornell Agricultural Station

FIG. 456. How many important environmental factors can you name which have improved these cows on a model farm?

In the last thirty years considerable progress has been made in improving the plant along special lines. The work done depends on the particular characteristic the breeder wants to bring out in his plants. In one set of experiments he works for a higher oil content of the seed, in another, for bigger and stronger plants; in still another he tries to produce a seed with a greater protein content, or seeds that are tender or of superior flavor; or he strives to obtain a variety immune to disease. If, for example, he is interested in improving the oil content of the seeds he will discover great variation in this respect. You would say his plants are probably of different genetic make-ups. Some have combinations of genes that make for high oil content, others have combinations that produce low oil percentages, and many fall between these extremes. The breeder, therefore, looks his crop over carefully, measuring, weighing, and analyzing for oil content. Having found some plants that are superior he keeps their seed for his experiment. He plants this "best" seed and from this new crop he again selects. This may be repeated for several generations. By this selection he merely separates out the plants with the most desirable genetic make-up as regards the amount of oil in the seed. By self-fertilizing in each generation he makes sure that no new genes are introduced. Thus he obtains a plant which has the desirable gene combination and which is pure for this character. This improved variety or strain of soybean will breed true because in this case the improvement was not acquired through the environment. But you can see that indefinite improvement in high oil content is not possible by this method, for after a period of selection the best possible combinations of genes will have been obtained, and the breeder can go no farther. *Exercises 2, 3, 4.*



Courtesy U. S. Bureau of Plant Industry

FIG. 457. These strawberry plants were selected out of the whole field as desirable for breeding. The others were destroyed by the breeder.

Inbreeding and outbreeding. By *inbreeding* or *close breeding* is meant the crossing of two individuals that are closely related. "Inbreeding" occurs among human beings when cousins marry because these cousins have two of their four grandparents in common. Among animals the two offspring of the same parents are often crossed; this is still closer inbreeding; and among such plants as peas, tobacco, and wheat, where self-fertilization is normal, inbreeding is closest because the egg and sperm come from the same parent.

For a long time it was thought that, except in the case of those plants in which self-fertilization is normal, inbreeding was not desirable, that it led to a decrease in vigor and size and often resulted in offspring that were defective in one way or another. There were many facts to support this belief. But there were also facts to disprove it, so that no sure conclusion was reached until an understanding of Mendelian heredity made it possible to explain both sets of facts.

Close relatives, since they come from the same parents or from the same grandparents, are likely to have the same recessive genes. When such close relatives are mated two recessive genes may come together and thus produce in the offspring a character that was hidden in each of the parents. If this is an undesirable character the inbreeding results in poor offspring; and since many undesirable characters are recessive inbreeding is often disadvantageous. If there are no undesirable recessive genes in the two individuals that are crossed, the inbreeding can do no harm; and if the parents have many desirable genes, inbreeding is advantageous; it prevents the introduction of less desirable genes. When plants and animals are inbred and undesirable offspring are obtained they can be destroyed, so that in each generation the breed becomes more nearly pure for desirable genes. Except in the case of self-fertilized

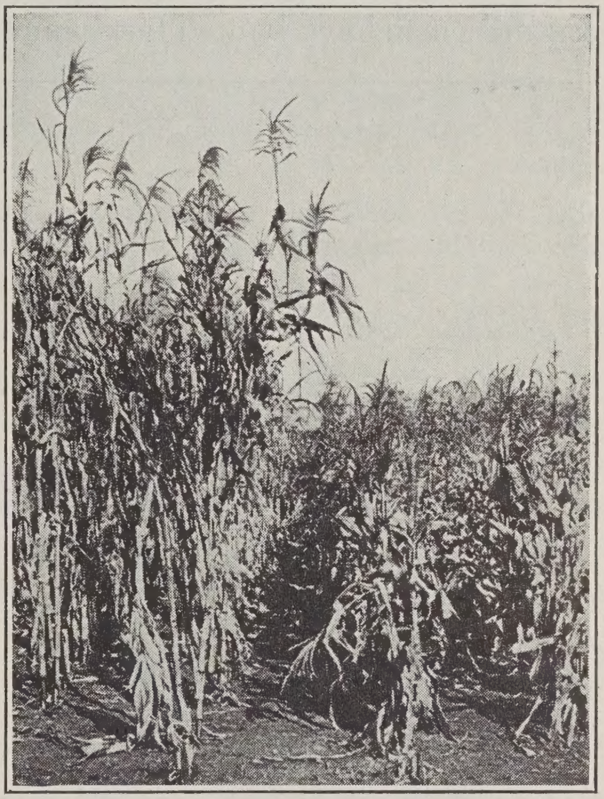


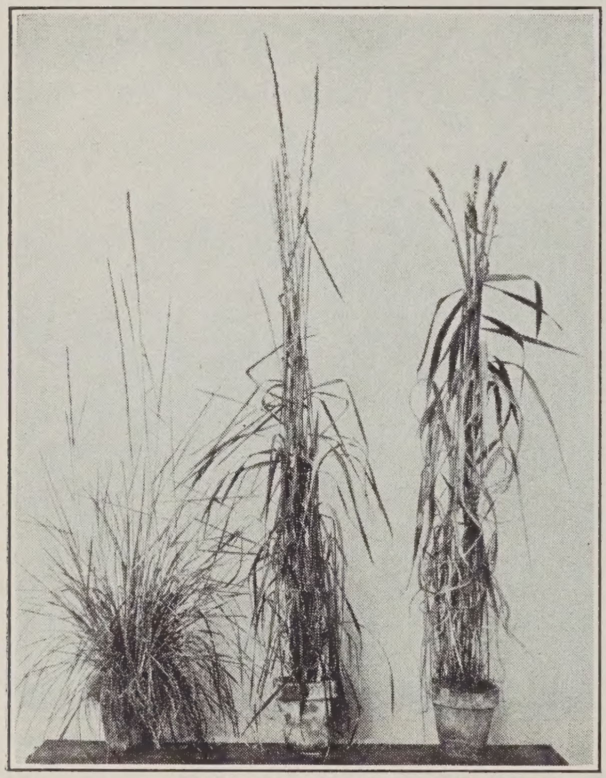
Photo Science Service

Fig. 458. In experiments at the University of Illinois, breeders selected from one field of corn some plants for tallness and some for shortness. After several generations of selection these two varieties were obtained.

plants, however, the inbreeding has never gone on long enough to produce organisms that are pure in all their characters.

In *outbreeding*, the organism is crossed with another of the same species or variety that has no family connection. The breeder hopes that by doing this he can prevent undesirable recessive genes from coming together. *Exercise 5.*

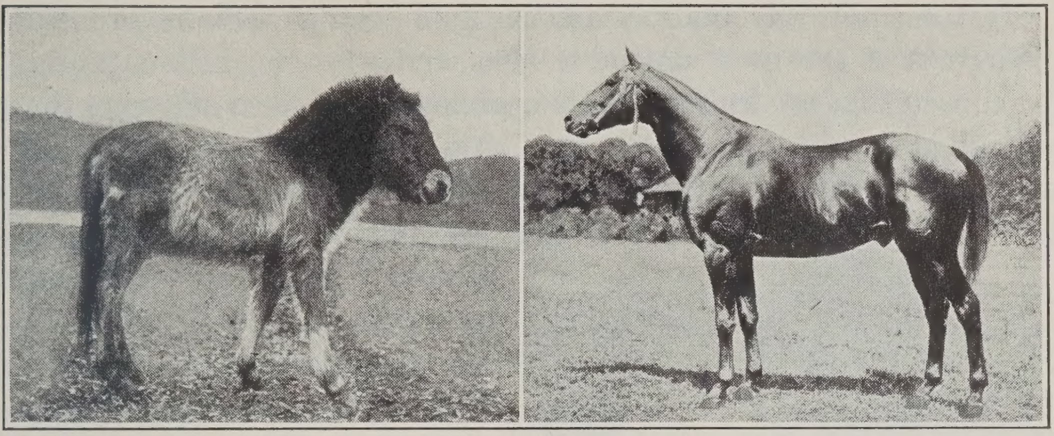
Selection and inbreeding improve animal types. For many centuries men have wanted fast-running horses, first for protection, then for sport. In every generation, they selected the fastest horses for breeding, often inbreeding them to keep desirable characters. The competition was so keen that men succeeded in improving the speed of race horses long before they had improved other domesticated animals to any great extent. In fact, selection has been practiced in horse breeding for so long a time that in recent years there has been little or no improvement in the records set by race horses.



Courtesy U. S. Dept. of Agriculture

FIG. 459. Wheat (right) crossed with another grass (left) produced the hybrid in the center. Hybrids frequently show increased vigor. How may outbreeding be desirable?

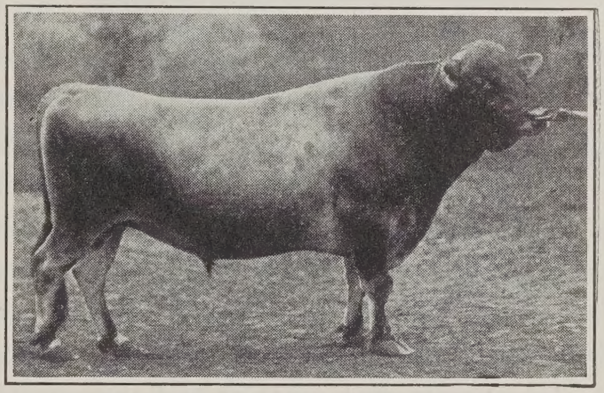
Among cattle, too, there has been improvement through selection. Thus in 1880 the record Holstein-Friesian cow produced 18,004 pounds of milk during the year. By 1920 this breed had been improved so much that a record of 37,381 pounds was set. This doubling of the amount of milk given was accomplished largely by the careful selection of the best genetic combination in each generation and the use of these animals for breeding. It is true that if this record-holding cow of 1920 had not been fed and cared for by all improved methods her milk production would have been considerably less. There were two factors operating to-



Courtesy U. S. Bureau of Animal Industry

FIG. 460. How does this wild horse from Asia (left) differ from the thoroughbred? Can you name other breeds of horses improved along different lines for special purposes?

gether: the continued selection of the most desirable animals for breeding purposes, which improved each new generation, and the improvement of the environment which enabled each individual to make the best of its good genes. *Exercise 6.*

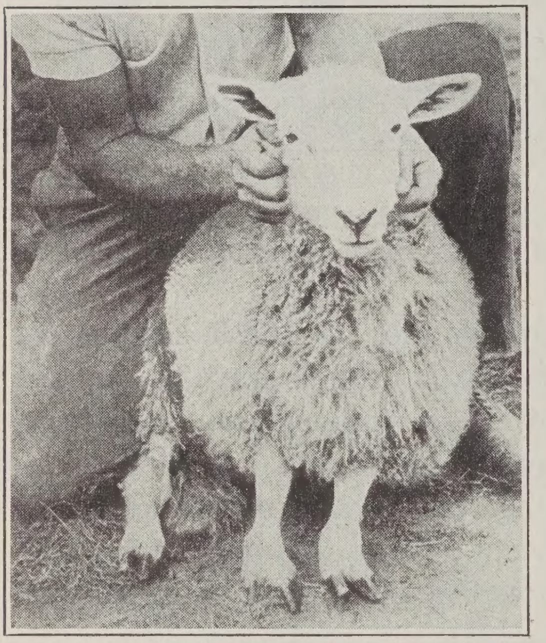


Courtesy U. S. Bureau of Animal Ind.

FIG. 461. This purebred bull is valuable because he carries genes for the production of milk rich in butter fat. His daughters always exceed their dams (female parents) in the production of butter fat.

Breeders keep careful records so that the exact ancestry, or *pedigree*, of every animal is known. The names and descriptions of the animals that have improved stock can be found in the registries of the cattle breeders' associations. From these records one can learn which animals have produced the best offspring; it is these, rather than the offspring, that are kept for breeding purposes. For example, since it has been discovered that bulls transmit to their daughters the characteristic of producing much or little milk, accurate records are kept of the milk-producing ability of the daughters of a purebred bull. If a certain cow is a good milk producer, her sire (male parent), rather than the cow herself, is used for further breeding.

In the same way poultry associations keep in their records the pedigrees of the most desirable hens and roosters. Parents may be chosen that are known for their ability to produce offspring that are good layers. However, this kind of selection has been less generally practiced with poultry than with cattle. As a result the average yearly production of eggs per bird is only about eighty although there are registered hens that lay four times as many eggs per year.



Courtesy Storrs Agric. Exp. Station

Fig. 462. An Ancon sheep used in breeding experiments. This mutation occurred a second time in a flock of a Norwegian farmer many years later.

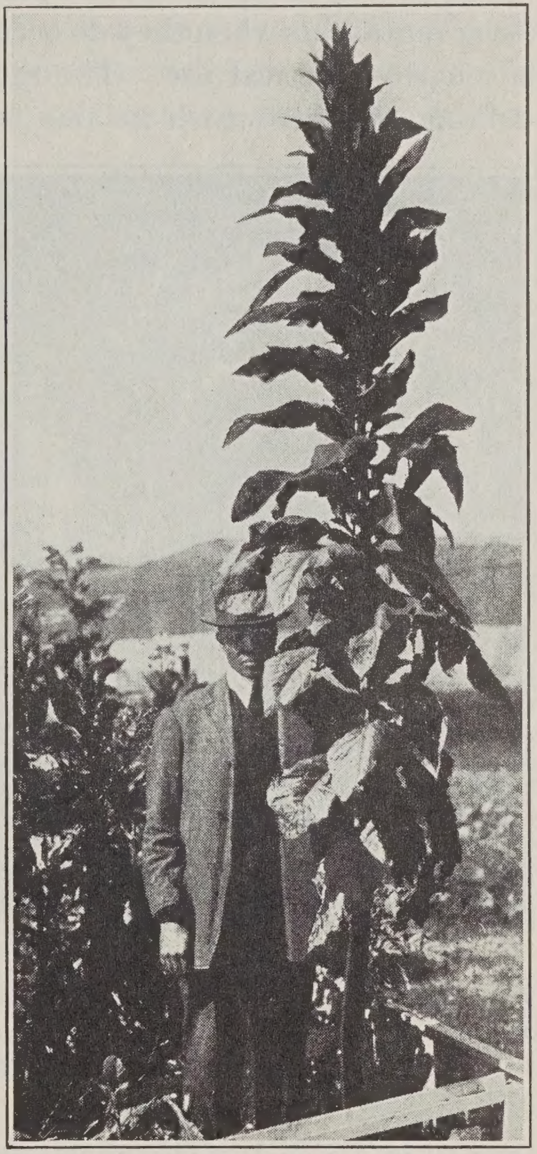
Breeders make use of mutations and other chromosomal changes. A short-legged lamb was born on a New England farm in the latter part of the eighteenth century. The farmer kept this lamb for breeding in the hope of establishing a new breed of sheep that would be too short-legged to jump fences. He was successful in starting the Ancon breed, for the new character bred true. Because this character had never appeared before in the ancestors of this sheep, as far as was known, and because it was inherited, it is assumed that short-leggedness was the result of a mutation or other chromosomal change. As fence-building became easier and other qualities seemed more important the breed was permitted to die out.

Another mutation that has occurred several times is hornlessness in cattle. The polled (hornless) condition is desirable because such cattle are easier to handle. Breeds of polled cattle are now being established. Other mutations in animals have been recorded.

Mutations occur more frequently in plants than in animals. Plants as a rule have so many offspring that the chances for the occurrence of a mutation or other chromosomal change are relatively greater than they are in animals. Thus in Maryland there appeared recently a tobacco plant that has become the parent of the Mammoth type. If grown under long hours of sunlight, it always reaches a great size. It is thus a new and more useful type of tobacco plant which may replace other varieties.

In 1910 in Boulder, Colorado, a common wild yellow sunflower produced a red blossom. This was the beginning of a new variety; the redness was caused by a gene or chromosome change. New flower colors frequently seem to arise in this way. In 1849 at Concord, Massachusetts, a more desirable grape, the "Concord," arose from a single seed of the wild grape.

In plants, the mutation often occurs in some part of the developing plant such as a branch or stem instead of in the gamete or fertilized egg. Breeders speak of this as a bud variation. For example, on an ordinary orange tree there appeared many years ago in Brazil a branch that bore seedless oranges. This mutation, really a bud mutation, started a new variety.

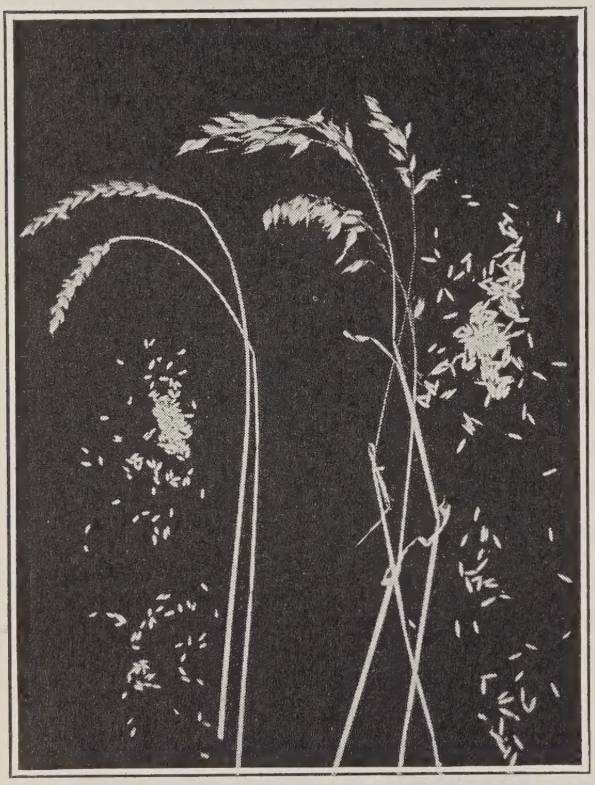


Reproduced from Yearbook of Agriculture, 1936

FIG. 463. This mammoth tobacco had 112 leaves when photographed. It arose as a mutation from parent plants like those seen on the left.

In 1934, in the United States experimental vineyard at Fresno, California, a center for raising small seedless grapes, one of the vines was found to have a branch that bore two clusters of much larger grapes. These large grapes proved to contain seeds. Experiments showed that they were mutants. This mutation, while interesting from the scientific point of view, is commercially unprofitable. Naturally, undesirable gene and chromosome changes are just as likely to occur as desirable ones. In fact, as you have already learned, mutations are often of such nature that they do not even permit the organism to live.

One of the functions of the plant and animal breeder is to discover mutations when they do occur and to see how the change may be put to practical use. The mutations described above are all striking changes which no one could fail to observe, but mutations are not always so easy to see and alertness is required if the breeder is to meet with success.



Courtesy Am. Mus. Nat. Hist.

FIG. 464. Heads of wheat on the left; oats on the right. Next to each are the grains. How would you go about raising a variety with larger heads?

Better varieties are often found in other countries. In the early days when our country was still unsettled seeds or plants were frequently brought by immigrants or sent by friends from the old country. In this way useful varieties were sometimes introduced. More recently Agricultural Experiment Stations have made a regular practice of hunting for desirable varieties abroad. The wheat that covers thousands of acres in our cold North Central States developed from a few seeds which started in Poland; from there some of the seeds were carried to Germany where they were planted and produced more seed. Some of this seed was taken to Scotland. A Scotch farmer sent a small sample of the wheat to a friend, David Fife, who wished to experiment with the planting of this variety in Canada. A single plant of spring wheat developed. David Fife saved the seed carefully and from this came all the wheat known in Canada as Red Fife. From Canada it was brought to the United States.

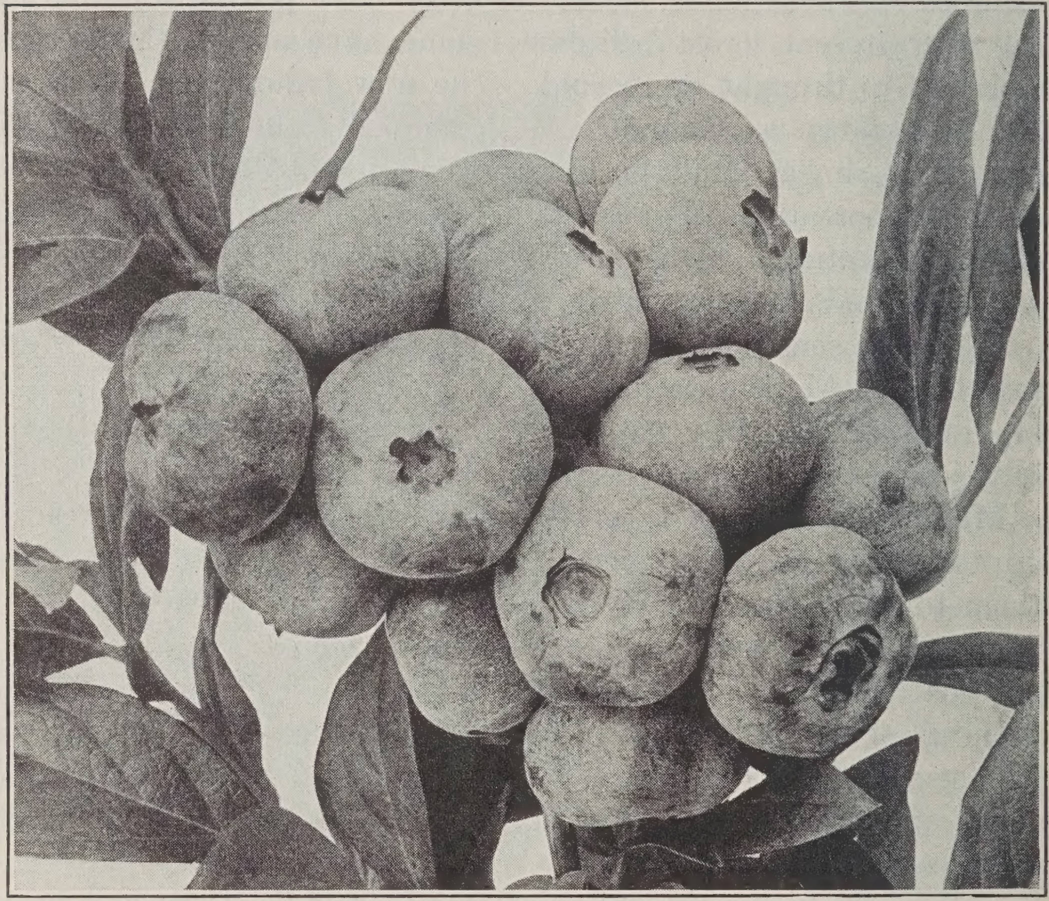
One good drought-resistant variety of wheat was brought from

Russia by early settlers in Kansas. Seeing the success of this variety, M. A. Carleton of the United States Department of Agriculture went to Russia in 1900 deliberately to search for still better strains. Since that time the Department of Agriculture has brought into the country and tried out more than 8000 different samples of wheat alone. Some of these have proved immune to the ever-present "rust" disease; some have shown themselves resistant to drought or to cold. The now famous red wheat of Kansas, known as Kanred, was developed from a lot imported from the Crimea. But the Kansas Experiment Station improved on the importation. For ten years scientists watched the wheat closely, selecting for the next year's planting those individuals which showed the greatest resistance to rust. *Exercise 7.*

Explorers sent out by the Department of Agriculture are now searching in Manchuria and Mongolia for drought-resistant, soil-binding plants. These expeditions will more than pay for themselves if just one highly desirable plant is found. *Exercise 8.*

Making new plants to order. In the early days the breeder improved his plants by selecting the best types, and then getting them to breed true. Now he is no longer content with what he finds at home or in foreign lands but tries to create an ideal plant, one that suits him in all respects. For example, Dutch scientists in Java set themselves the problem of creating a new sugar cane. The scientists wanted a cane with an exceptionally high yield of sugar and one that was resistant to the many insect and plant enemies that injured the cane. Within three years they were successful in producing the famous "P.O.J. 2878." They had been raising a cane rich in sugar but particularly susceptible to disease; the wild plant, though resistant to disease, contains almost no sugar. These two were crossed, or *hybridized* as the breeder would say, and among the offspring some were found that had a combination of the two good qualities. These were selected as parents for the next generation. Then these new individuals that possessed one desirable character from each parent were crossed with other cultivated varieties which provided various other desirable genes. Thus the scientists put together into one plant a combination of genes which had never existed together before.

In this country breeders have been able to produce a watermelon which is disease resistant, is covered with a rind which is thin but tough enough to stand shipping, has flesh of the right quality, and is full of juice. They took as one parent a variety of watermelon, known as citron, which cannot be eaten but is immune to disease. The other parent was good in quality of flesh and taste but susceptible to disease. Since several genes were involved, the F_1 plants were complex hybrids. The breeders selected a few and hybridized again. From among the three or four thousand offspring of the F_2 generation they selected ten which showed a combination of the desired qualities. After five years of such selection and hybridizing, the desired variety, named the Conqueror, was obtained.



Courtesy U. S. Dept. of Agriculture

FIG. 465. These blueberries are a little over one inch across but they lack flavor. This plant has been hybridized with a plant known for its flavor. Selection was practiced. One bush now exists whose berries combine size and flavor. How must this new plant be tested before it can be said to be a successful creation?

The American breeder, Luther Burbank, is famous for the many new forms he created through hybridization. Desiring a cultivated daisy that should be hardy and have large showy blossoms he crossed the sturdy but modest appearing American wild daisy with the less sturdy large-blossomed English daisy. When after several generations of selection and hybridization he had obtained the desired combination he crossed it with a Japanese daisy which is noted for the whiteness of its flower. In this way another desirable gene was introduced, and the result was the "Shasta" daisy named after California's giant snow-capped peak. *Exercises 9, 10.*

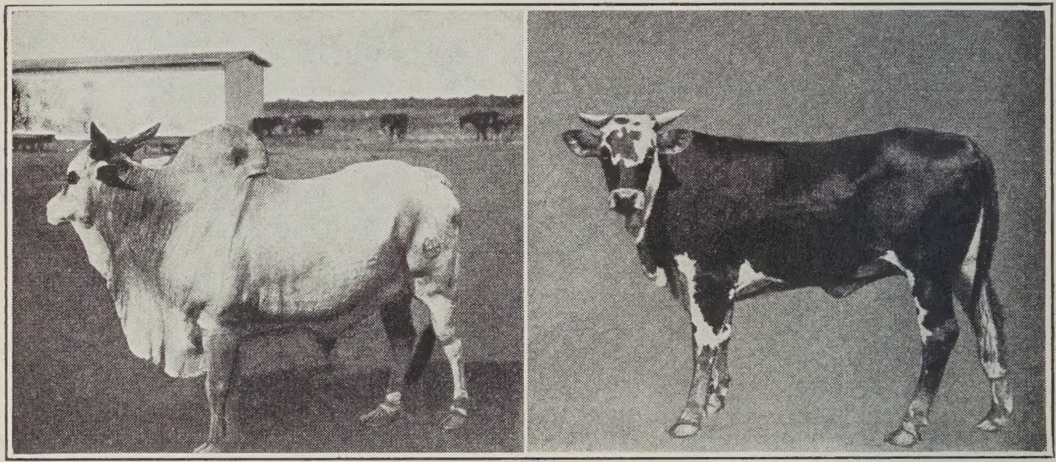
At the Plant Breeding Station in Sweden experiments have been carried on in wheat breeding which have increased the yield by 40 per cent. The old Swedish strains withstood the cold and the flour was good for baking bread, but the yield was small. These strains were crossed with the English Squarehead wheat which had nothing to recommend it but its high yielding power. After some generations a form appeared which had a combination of the good qualities of both parents.

Very often, to be sure, the breeder's wish is not fulfilled. It has been difficult to produce completely desirable strains of oats because one desirable character, the presence of many seeds on a stem, seems to be linked with undesirable qualities. Therefore when the breeder uses as one of the parents the variety with many seeds he is bringing into the combination of genes some which he does not want.

Making improved animal types to order. Some years ago an interesting hybridizing experiment was carried on in Texas. The good beef cattle seemed unable to endure the intense heat of summer in the Gulf regions and died of Texas fever. Brahman cattle had been imported into the United States from India on various occasions previously. They were well adapted to the climate of southern Texas and did not get Texas fever but they could not compare with our American breeds in quality of meat. Some of these Brahman cattle were crossed with several types recognized as good beef cattle and after some fifteen years of crossing, back-crossing, and selecting, a Brahman-Shorthorn breed was developed. This breed combines the good qualities of both ancestors. Because of considerable inbreeding it is now reasonably pure and therefore breeds true.

At present similar experiments are being carried on in Louisiana in the crossing of Africander cattle from South Africa with our native beef cattle. The results of these crosses promise to be even more successful than the earlier Brahman-Shorthorn crosses.

The sheep raiser wants a breed that produces wool of good quality in large amounts, that has satisfactory amounts of good meat, that is hardy and resists disease. So far less progress has been made in obtaining this ideal combination. There are still many problems for scientists to solve in regard to inheritance in sheep before practical results are possible.



R. K. Nabours, Kansas Agricultural College

FIG. 466. On the left Brahman bull. What characteristics does it possess besides resistance? On the right the F_1 resulting from a cross between Brahman and Hereford cattle. Which characteristics did the Brahman bull fail to pass on?

Within recent years breeders have become interested in crosses between rather different species of animals. Of course the mule, the hybrid offspring of the horse and the donkey, has long been bred and has proved itself successful. With rare exceptions, the mule is sterile (cannot produce gametes). At present the American bison is being crossed with domestic cattle. The offspring, known as the cattalo, may at some time become commercially valuable. The crossing of goats with sheep has been less successful.

Plant breeders make good use of vegetative propagation. You have learned that many kinds of flowering plants reproduce asexually by vegetative propagation as well as sexually. In such a case, fertilization and seed formation need not occur. Some vegetative organ, the root, the stem or the leaf, produces a whole new plant. Since there is no fertilization and no new genes are introduced, the plant produced by vegetative propagation will, of course, have the same genetic make-up as its parent. Where the breeder has obtained a particularly desirable combination of genes by hybridization, it may prove difficult to establish a pure type. It will take a long time before the new hybrid produces descendants that are pure and that will breed true. But, if the desirable hybrid can be propagated by *cuttings*, every *slip* or cutting will have the same desirable gene combination.

When dealing with plants that have woody stems, *grafting*, instead of slipping, is often practiced. This consists in attaching a small twig to a branch of a growing plant. The small stem that is cut off, known as the *scion* (sy′on), is placed against or in the stem of the rooted plant in such a way that the growing layer (cambium) of one is in close contact with the growing layer of the other. To prevent infection and too much loss of water the two parts are bound tightly together and waxed. After a short time the scion grows onto the *stock*, forming a part of that tree or shrub. Sap from the stock nourishes the scion and if the stock is a particularly vigorous one the scion will profit by the activity of the stock. Naturally, the genes of the scion and the genes of the stock remain unchanged. When the cells of the scion divide and the scion grows it will keep the genes (characters) it had before it was grafted. The same is true of the stock. In other words, grafting is not a method of hybridizing. But it is a convenient way of propagating

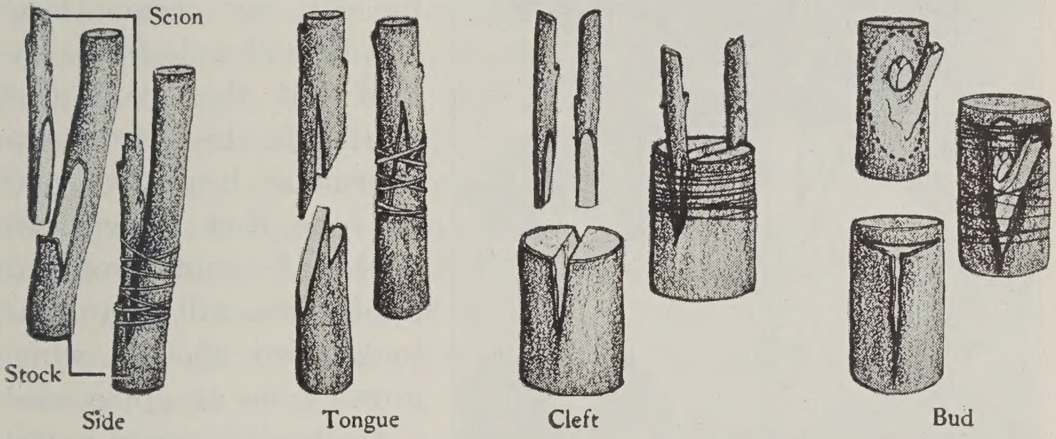
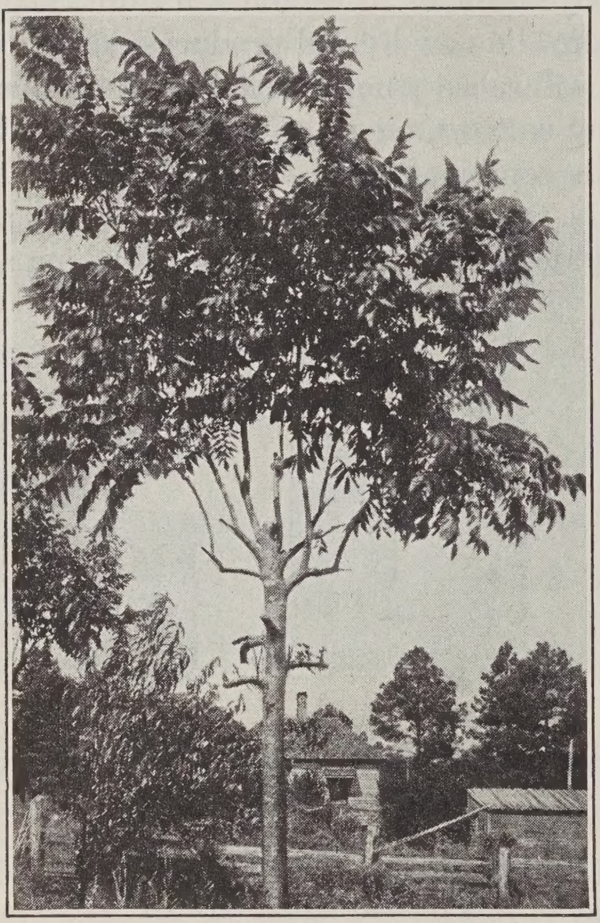


Fig. 467. There are many ways of grafting the scion to the stock. What is provided for in each case?

or obtaining more of a certain type of plant, for the grafted scion grows larger every season. If a breeder has a plant with a particularly desirable combination of characters he can graft many such scions on other stock and be sure that, normally, the desirable characters will continue to appear in every scion. The McIntosh apple and the oxheart cherry are always propagated by grafting.

Not only do grafting and other forms of vegetative propagation enable the breeder to obtain large numbers of a desirable hybrid but the plant that starts life this way has an enormous headstart over the one that grows from seed. A scion from an apple tree will bear fruit long before the tree which grows from an apple seed.



Reproduced from Farmers Bulletin, U. S. D. A.

FIG. 468. A pecan stock has been grafted with pecan scions of a better variety. How many scions were grafted? The grafts were made on Aug. 10; the lower branches removed on Sept. 1. Why was it not all done at one time?

Grafting is useful in still another way. When the first seedless orange appeared as a bud mutation a scion was grafted on an ordinary orange tree. The scion grew and branched; twigs were again cut off and grafted. Soon so many grafts had been made that there were whole orchards of trees bearing seedless fruits. In fact, every seedless orange that you eat must have come from some graft, for if no seeds are produced no seeds can be planted to produce more of these highly desirable fruits. The seedless orange is an example of a mutation which would have died out had man not been there to preserve the mutation by grafting. *Exercises 11, 12, 13, 14, 15, 16.*

The production of new species of living things. You have just learned that the science of genetics has provided man with a tool by which he can change organisms almost as he wishes. You have read that breeders are now able to produce new varieties of plants and animals which are better than the old. The science of genetics is thus shown to have great practical value. But in the hands of scientists in the laboratory, the same methods have been used for purposes that have little practical value. These scientists have attempted to produce new types of organisms experimentally to see to what lengths they might go. In these experiments they have tried to produce not only new varieties of existing forms, they have tried to produce types of organisms so different from the old that they may be called new species. Despite the enormous difficulties, their attempts have been successful. In one of the first of such successful experiments two American biologists succeeded in crossing two species to produce a hybrid that could reproduce but could not be crossed with either of the parent plants. The new plant had as many chromosomes as both parents put together. Its structure was different, as you can well imagine; it was a new combination of characters, some of which came from one parent, some from the other. Other biologists in this and other countries have succeeded in duplicating this feat with other plants.

It is clear that not only new varieties but new species may arise under man's eyes. In bringing this about man has employed natural methods, but his understanding of genetics has enabled him to direct and control and thus to speed up the rate at which new kinds of plants and animals appear. *Exercise 17.*

Exercises

1. Visit florists and fruit and vegetable markets. Find out from your parents which plants have been introduced since the days when they were young. Compare with the lists brought in by your classmates.

2. For some purposes corn should be low in oil content; for others, high. If a breeder had an otherwise desirable variety whose grains yielded what is considered a medium amount of oil (from 3.84% to 6.02%), what steps would you recommend that he take to obtain corn with a high, and corn with a low content?

3. If you were raising strawberries and they were being given the most suitable soil, moisture, temperature, and light conditions, what would you try to do next to improve your plants? State specifically what you would consider desirable characters in a strawberry plant.

4. If the genetic make-up of a plant is *Ts* and it is self-pollinated, what offspring might you expect? How could you get a pure strain of tall plants?

5. Can you demonstrate with two living flowers how the breeder would cross-pollinate them artificially? What precautions must be taken?

6. Between 1880 and 1920 the record for milk production advanced from 18,004 to 37,381 pounds per year largely through careful selection. What would you expect the record milk production to be in 1938 if similar methods were used? Explain your answer.

7. Read about plant breeders in De Kruif's *Hunger Fighters*, and write a report.

8. Can you explain why the Department of Agriculture should send scientists to Mongolia and Manchuria rather than to France and Germany?

9. A breeder has two varieties of apple trees. One bears sweet green apples and the other sour red ones. He discovers that he would have a market for sweet red apples. What could he do about it? Would he be sure of success?

10. Old seed catalogues for which a commercial firm no longer has any use often give much interesting information on improved vegetable or flower types. Let the class secretary write for some.

11. Can you state five distinct reasons why the plant breeder can make more progress than the animal breeder?

12. If your class were divided into committees you might obtain much interesting information about the work done by your State Agricultural Experiment Station, about the Department of Agriculture at Washington, the Bureau of Animal Industry, the Bureau of Plant Industry, the Cattle or Poultry Breeders' Association of your state, local Granges, and so on.

13. Let your imagination create some plant or animal type that would be desirable in the future. Give several reasons why such a form might be made to order now when it would have been impossible a hundred years ago.

14. Why is the breeder's notebook more important to the biologist than the desirable new fruit he produces?

15. A plant breeder nowadays can take out a patent on some new "creation" if it can be propagated vegetatively. Discuss the desirability and undesirability of the law permitting plant patents.

16. Would you be interested in finding out how to prepare yourself for work of this kind? Your State Agricultural College will give you information.

17. *Summary.* Summarize this subject from two points of view; first from the point of view of economic importance, giving definite facts and examples. Second, summarize from the point of view of biology, explaining each method used in improving plants and animals. How does this section show that new kinds of plants and animals may arise from old?

Activities for the Junior Biologist

1. It is interesting to read how and when the various animals were domesticated. Report to the class.

2. Ask your school library to write to the Department of Agriculture for its annual yearbook. You will read of much interesting work that is being carried on. Choose one topic and report to the class.

3. If you have a garden and are ready to carry a long experiment through to completion you can do breeding experiments of your own. Careful records are all-important. Certainly you can learn to graft. Ask your teacher for help.

4. With more space and a chicken pen you can breed for increased egg laying.

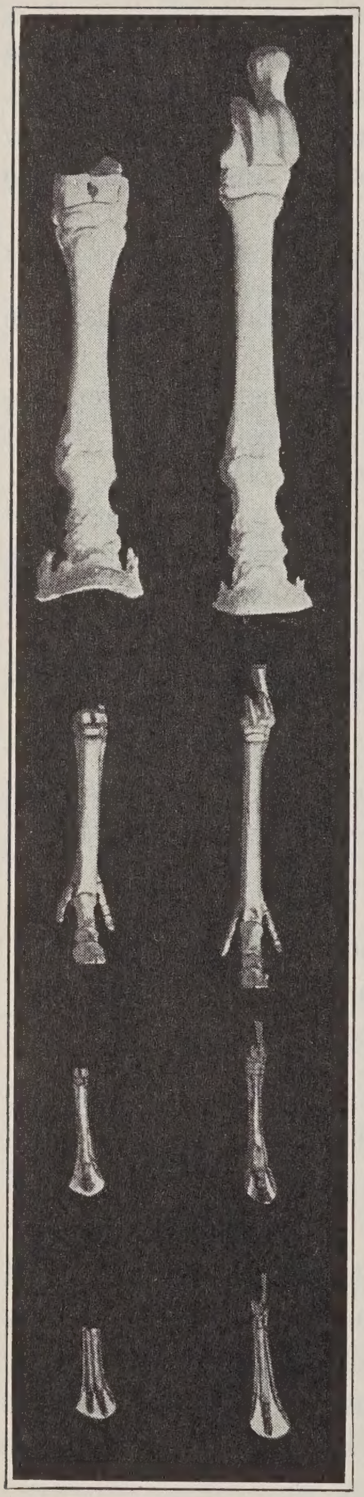
5. Many newspapers give descriptions and pictures of the many breeds of dogs. Make a chart placing together the dogs that are most similar. Consult D. C. Ash's *Dogs: Their History and Development.*

2. The Sequence of Fossils in the Rocks Indicates That the Various Types of Plants and Animals Originated from Different Types That Preceded Them

How one set of facts ties up with another. You have just learned that during the several thousand years of written records man has produced new and, for his purposes, better types of plants and animals. He has created new varieties of cultivated plants and domesticated animals. You have learned, too, that within recent years man has gone even further. In genetics laboratories new forms have arisen so different from those from which they were produced that they must be classified not merely as new varieties but as belonging to a new species. Man has seen living things change under his very eyes.

You will recall that in an earlier unit you learned that the earth and its inhabitants are always changing. You saw the earth as it must have looked at various periods of its history. You saw it first without any life at all; then with its oceans swarming with invertebrates of many kinds and simple plants, its continents a rocky waste; then you saw the earth with vast forests of tree ferns, with fish in the waters and amphibia and reptiles inhabiting both land and sea; you saw it next with huge reptiles, dinosaurs, which had taken possession of the land; and finally you saw it much as it is today with all the vast number of animals and plants, many like those of earlier periods but new ones, too, the birds and mammals. Each scene was very different from the last.

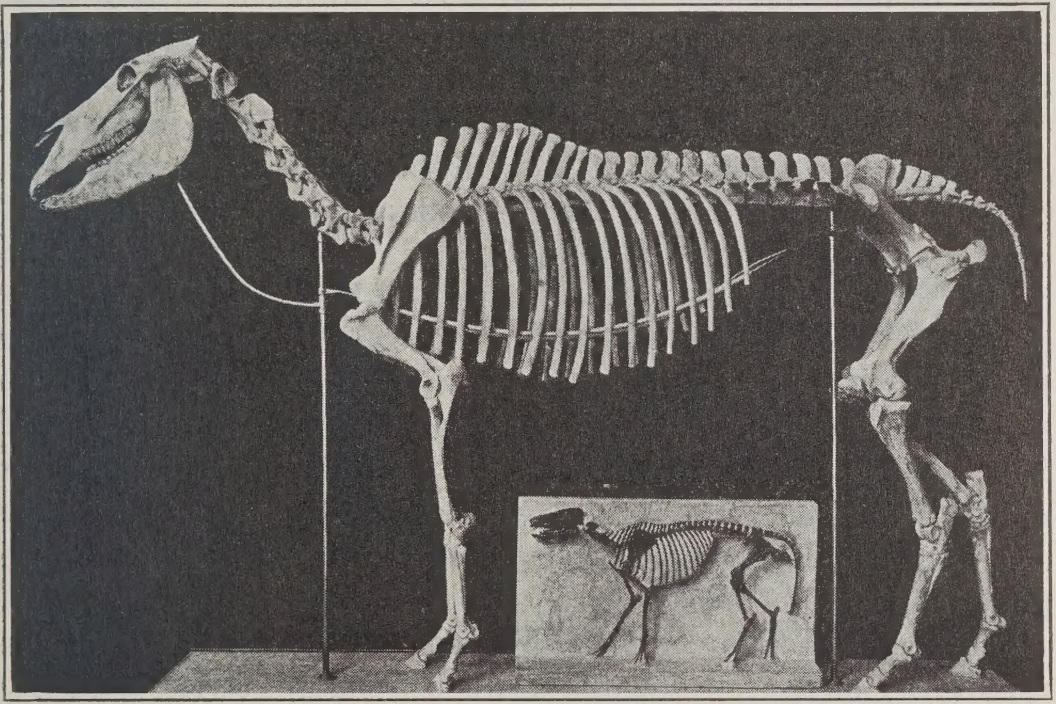
Biologists have put these two sets of facts together; what the breeder sees at his experimental farm and laboratory and what the paleontologist sees in the rocks. They have asked themselves whether it is possible that the small changes of which we have records during historical times have been duplicated, but on a much larger scale, during the countless ages of earth history? For example, it is known that the horse, during the history of man, was changed from the small wild horse to forms large of frame and able to haul heavy loads and to forms that are tall with long legs and light frames for swift running. Is it possible that the horse changed before the days of written history and that, because these ages lasted many millions of years, the changes were far greater than those noted in the horse since it has been domesticated? The answer to this question has been found in the rocks containing fossils.



Courtesy Ward's Nat. Sci. Est.

FIG. 469. In the lowest strata belonging to the age of mammals are found leg bones like those shown at the bottom. In somewhat higher (more recent) strata were found those in the second row, and so on to the top. Do you recognize the bones?

What a close study of the rocks teaches about the history of the horse (*Equus caballus*). That the horse roamed over this continent a half million years ago is sure; it has left its bones in the topmost layer of the rock. Paleontologists have had no trouble in recognizing these fossils; they have found specimens of the characteristic long leg bone of the horse. This bone ends in one large lengthened single toe developed into a hoof with a small splint of a toe bone on either side. They have found, also, the characteristic skull with its complex grinding teeth which are different from those of any other grass-eating animal.



Courtesy American Museum of Natural History

FIG. 470. Skeletons of the modern horse and Eohippus to show comparative sizes. What resemblances between the two organisms can you see?

As expeditions explored the rich fossil beds of Wyoming and Montana they uncovered more fossils of greater or smaller resemblance to the horse. Although the work is still going on, there have already been obtained fossils from layers of various ages that tell an astonishing story. The fossils arrange themselves in a series. Down at the beginning of the series is a curious small animal, *Eohippus* (ee-oh-hip′pus), which is now believed to be the ancestor of all the horses of today. It lived here 60 million years ago. Until scientists found other fossils intermediate between it and the modern horse no one would have thought of connecting Eohippus with the horse. The little Eohippus was about as big as a cat or fox terrier, with four toes on the front legs and three on the back and with simple teeth that had no cement.

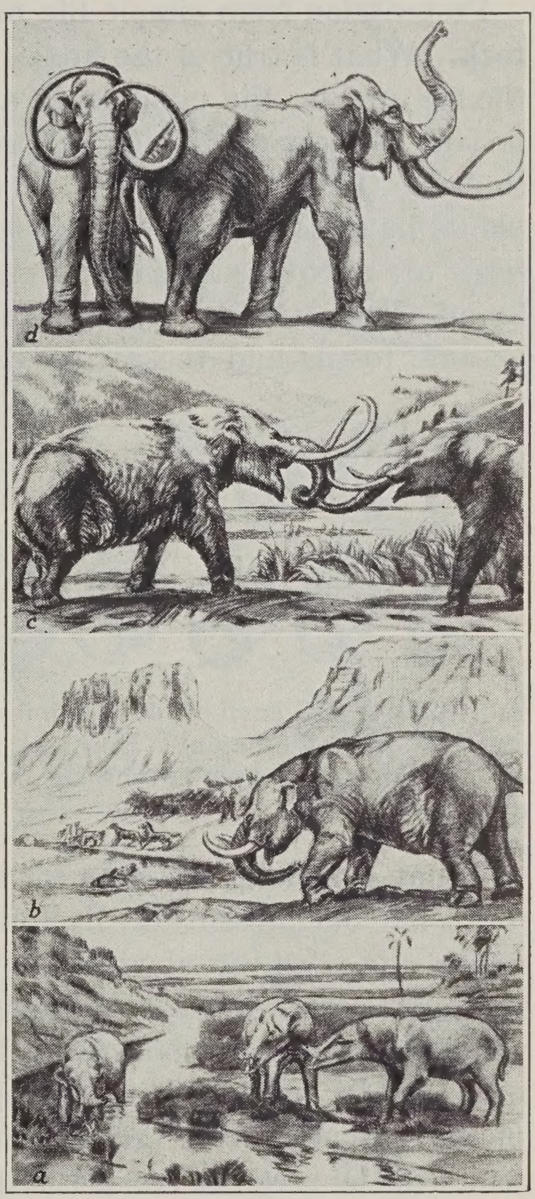
In the layers of rock above those containing Eohippus are fossils of an animal which bears a close resemblance to Eohippus, but differs from it in several ways. It stood higher and the middle toe on each foot was larger; its teeth were slightly more complex. The fossils in more recently deposited layers are even larger; they have three toes instead of four, with the middle toe still larger than before. The teeth are still more complex. These animals did not look much like the modern horse but still higher in the rock layers there are fossils of animals with the middle toe so large that it alone supports the leg as in the modern horse; the other toes remain as large splints. The teeth have cement with fairly long crowns. The animal is so much larger and looks so much like a horse that anyone can see the resemblance. There are more than a hundred species of fossil horses known, many of which can be arranged in a series showing that the horse of modern times must have come in a direct line of descent from Eohippus, that lived 60 million years ago. The changes that man has made in the horse are small compared to those that occurred in nature over a long period of time. *Exercises 1, 2.*

The importance of the fossil history of the horse. More than the history of the horse can be learned from this series of fossils. The series shows how one species of animal can change into another slightly different form and, how, later, this can change into still another, until, over a long period of time one animal gives rise to an animal altogether different from it. In such a series the last animal often cannot be recognized as the descendant of the first until fossils are found that fit between — transition forms, as they are called. In general, the longer the time during which changes occurred, the more unlike do the animals appear.

Other forms besides the horse have left a clear record of their ancestry. There are several important series of vertebrate fossils, although none as complete as that of the horse. One of these is the series that shows the development of the elephant from an animal that was only three feet tall and was without tusks or the flexible trunk.

Between this early form and the modern elephant there lived many transition forms. These fossils can be arranged in line to show that complex teeth, tusks, a long trunk, and great size are the results of the heaping up of many small changes over a long period of time. There are other related fossils showing structures that do not lead directly to the modern elephant.

Fossil series have been found that show the origin of the modern camel and pig, among the vertebrates. The ancestor in each case is an animal that would not readily have been recognized as the distant ancestor of the modern species. There are other fossil series that are extraordinarily complete. The sea urchin and the pond snail can be traced back through many generations of change to ancestors in the distant past. The changes are not as great in the invertebrate forms but, because of the large numbers of fossils present in the rocks, the steps from one form to the next are unusually small. Such complete series are particularly important to the biologist. They are almost as detailed as the written records of the laboratory and they extend over far greater periods of time. There are plant series, too. The plant fossils show changes that would seem unimportant to the untrained observer, but they show the scientist how one species may change



Courtesy Am. Mus. Nat. Hist.

FIG. 471. Restoration of animals in the elephant series. At the bottom is a small shovel-tusker whose remains have been found in Egypt. Above are later forms. What resemblances do they show?

into another and that into another and so on to the present-day types of plants. *Exercise 3.*

Progression from simple life to complex in successive layers of rock. What is true of the horse, the elephant, the camel, the pig, the sea urchin, the pond snail, and various types of plants must be true of every other kind of animal and plant. Series of fossils showing the direct changes in all other kinds of animals and plants have not been found. It may be a long time before such series are uncovered; it may well happen that they never will be found. This is not surprising, because comparatively few organisms became fossils and those that did were often destroyed by the folding and twisting of the rocks.

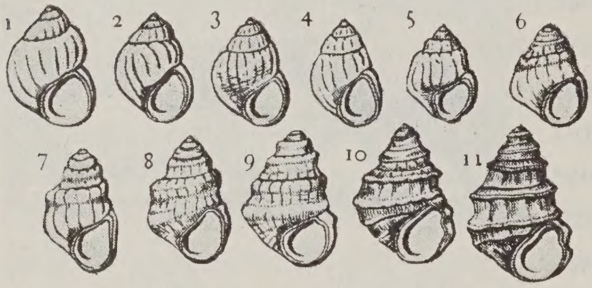


FIG. 472. Fossil snail shells. Numbers 1 and 11 look very different. Now look from each to the one next in line. What do you discover?

But turn back to the descriptions of the earth in the early Paleozoic, in the late Paleozoic (the age of coal formation), in the Age of Reptiles, and in the Age of Mammals and study with some care the animals found in each period. You will find a striking fact. In the lowest rocks are the single-celled forms like our present-day bacteria and simplest Protozoa. In the rock strata piled just above are simple invertebrates that inhabited the seas: corals, jellyfishes, sponges, animals like the starfish, and simple forms of arthropods. In a higher layer are found insects, the most highly developed of arthropods, fish, and some simple amphibia. Judging from the large number and variety of fish fossils found in the rocks of one period the fish were then masters of the "earth" although lower forms were still plentiful, as plentiful as they are now. In the rocks that show large numbers of amphibia the fossils of simple reptiles are found. Only in the rocks of a later period do the fossils of the many huge reptiles, the dinosaurs, appear. Small and much simpler reptiles lived for many years before the age when reptiles ruled the earth. But in the same rocks with the dinosaur fossils are the bones of a few simple mammals. In these rocks, too, fossils of birdlike forms occur. And in the still more recent rocks which completely lack the fossils of

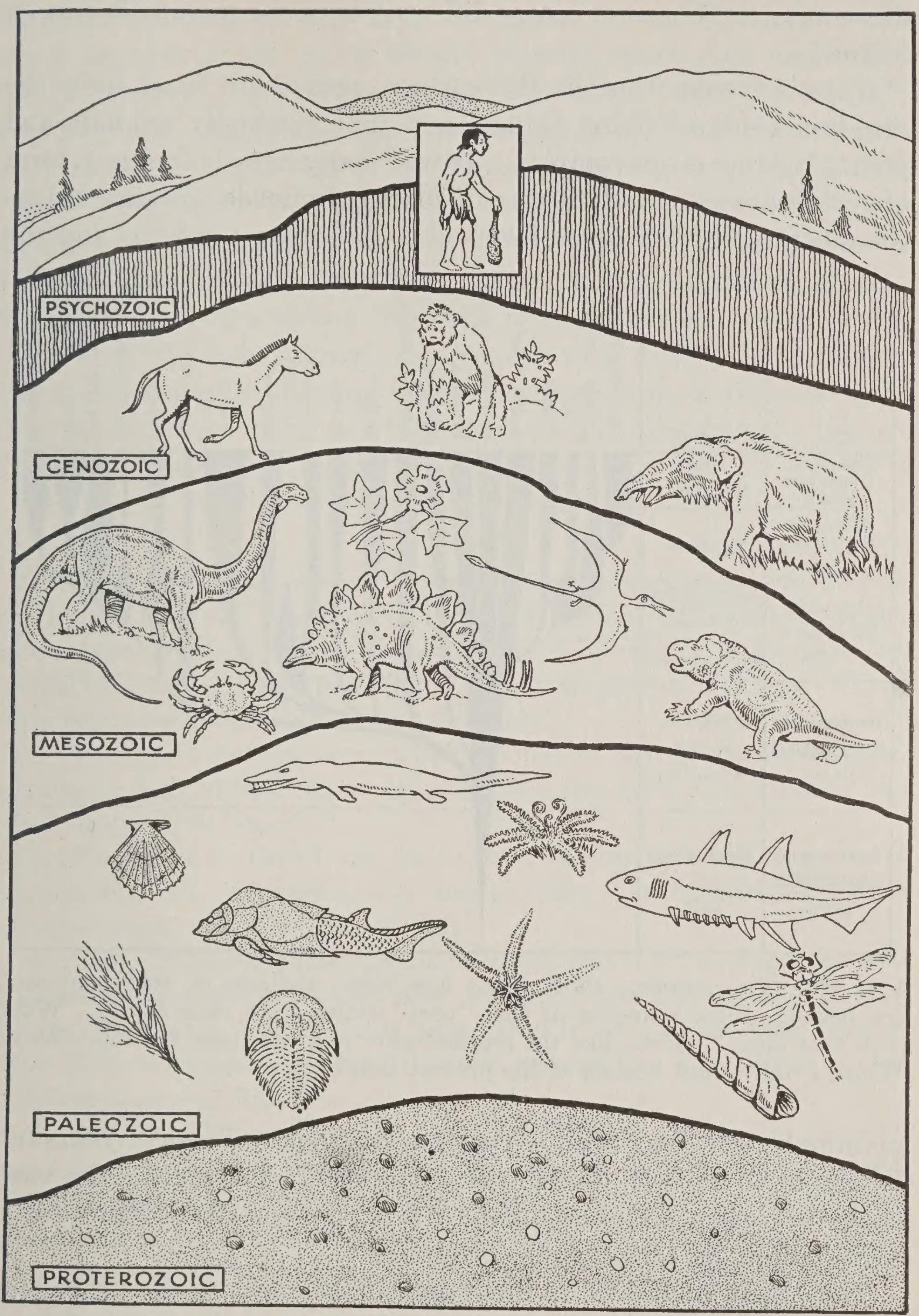

PSYCHOZOIC
CENOZOIC
MESOZOIC
PALEOZOIC
PROTEROZOIC

FIG. 473. Life throughout the ages of earth history. In each era are shown only a few forms, those whose fossils appear there for the first time. Where do you find the first fish, the first amphibia, dinosaurs, and mammals? Can you copy this simplified drawing and add other types to it?

dinosaurs, the bones of many different kinds of mammals can be found.

It would seem that in the earliest ages there lived only the simplest kinds of living things, and that gradually animals and plants became more complex. It was many ages before any form of vertebrate appeared; it was, of course, a much longer time before the most highly developed forms of vertebrates, the birds and the mammals, were produced. You know it took millions of years for Eohippus to develop into the modern horse. To produce the vast changes from a simple animal to a highly complex form took a correspondingly longer time. *Exercise 4.*

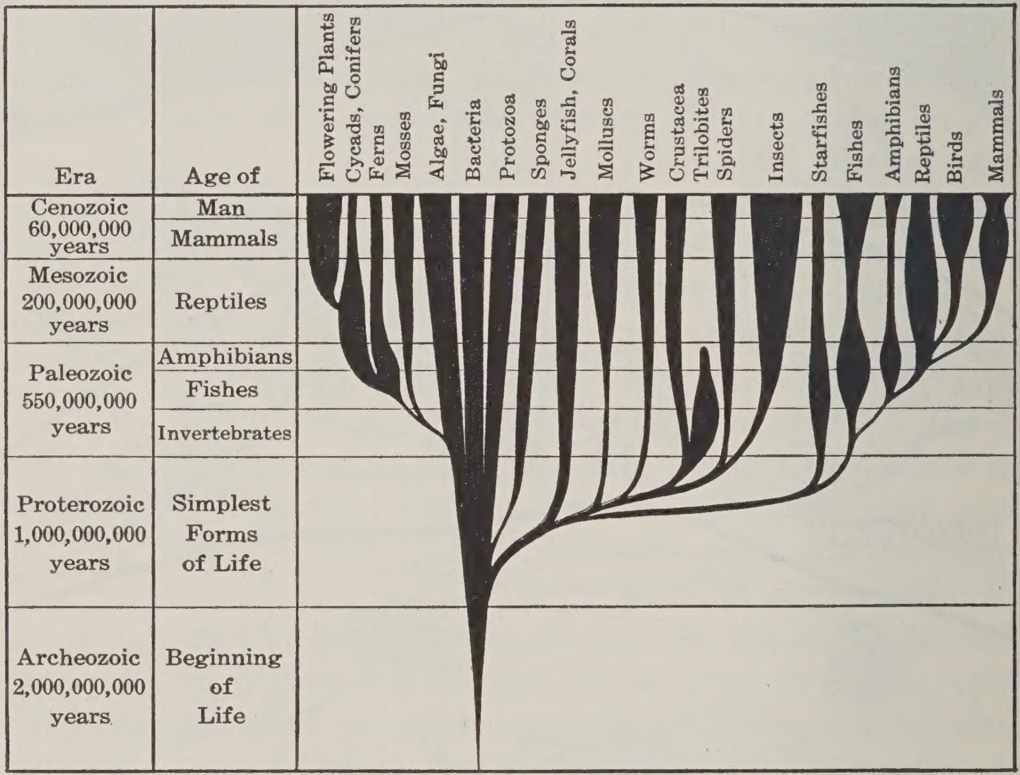

Era
Age of
Flowering Plants
Cycads, Conifers
Ferns
Mosses
Algae, Fungi
Bacteria
Protozoa
Sponges
Jellyfish, Corals
Molluscs
Worms
Crustacea
Trilobites
Spiders
Insects
Starfishes
Fishes
Amphibians
Reptiles
Birds
Mammals
Cenozoic 60,000,000 years
Man
Mammals
Mesozoic 200,000,000 years
Reptiles
Paleozoic 550,000,000 years
Amphibians
Fishes
Invertebrates
Proterozoic 1,000,000,000 years
Simplest Forms of Life
Archeozoic 2,000,000,000 years
Beginning of Life

FIG. 474. The numbers show about how many millions of years ago each era began. Some branches of this "tree" widen more than others. What does that mean? Some, like the reptiles, grow narrower near the top. Why? Which is the widest branch at the present time?

The "tree of life." A diagram can be used to illustrate the development of plants and animals throughout the ages. Sometimes this diagram is given the form of a tree; it is then called the *tree of life*. A very much modified tree of life is shown in Fig. 474.

In this diagram the types of animals now alive are shown by branches running to the top, or present era. It shows that some organisms are more closely related, some are more distantly related. If you trace their ancestry back far enough you will find that all living things have come from some common ancestor, some bit of protoplasm at the bottom of the "tree." Scientists know that it is not possible to trace the exact ancestry of an animal living now, for they could not trace it back a thousand million years. It is not of great importance, either. Scientists have discovered from the arrangement of fossils in the rocks that the first animals and plants were simple in structure and that each type of living thing originated from a different type that preceded it. This is a biological idea of the greatest importance. *Exercises 5, 6, 7, 8.*

Exercises

1. In the picture are shown four sets of leg bones, starting with Eohippus at the bottom. Many other forms have been found that fit in the spaces between the four sets. Draw a more complete series than is shown or describe the leg bones that fit in between those in the picture. What form might be found in still lower deposits?

2. The recent sedimentary rocks of Wyoming and Montana are comparatively undisturbed. How did this affect the work of building up the fossil series of the horse?

3. Turn back to Part 1 and list in order the invertebrate phyla, mentioning some common examples in each phylum. List in order the classes of vertebrates, with examples of each.

4. Using wrapping paper, prepare a large wall chart showing the geological eras by means of parallel lines. Fill in the names of the animals (and plants) the fossils of which have been found in each of the eras (consult Unit XII). Compare this with the list prepared in Exercise 3, above. Explain what you find.

5. Some fossil histories show that two different organisms probably came from a common ancestor, but the original form has not yet been found in the rocks. Such a missing ancestor, common to two different organisms, is called a *missing link.* Explain why the term link is used.

6. What important idea has been arrived at independently by the plant breeder and by the student of fossils?

7. What difference is there between the kind of evidence obtained by the breeder and that obtained by the paleontologist in regard to the changing of plant and animal types? Why are the records written in the rocks (fossils) more reliable than records written by man in early ages?

8. *Summary.* If you understand the meaning of the "tree of life" you understand this chapter. Explain the evidence on which the "tree of life" is based. Write an explanation of the "tree."

Activities for the Junior Biologist

1. If clay is available, prepare large models to show the evolution of the horse.

2. If one group of pupils is busy preparing models of the horse, another might do a series showing the evolution of the elephant.

3. If you can find the proper books as sources of information you might prepare models showing the evolution of other forms such as the camel, the pig, and the pond snail.

4. A series of drawings showing the development of plants through the ages would provide the class with an interesting bit of evidence.

5. What kind of evidence has convinced biologists that birds came from a reptilelike organism? Present it to the class for discussion.

6. The "tree of life" has been drawn in several ways by biologists. Prepare one or two. Explain them to the class. Sometimes there is fossil evidence that the descendants of a form changed in two directions, some giving rise to one kind of organism, others to another type. Can you show this in a tree?

3. Scientists Have Developed Theories to Explain How New Types May Develop from Preceding Types

De Vries's contribution. All scientists are now agreed that each species of animal and plant arose from some simpler type that preceded it. But there is no such complete agreement as to *the way* in which one organism can change into another. Most scientists accept the theory presented almost forty years ago by Hugo De Vries. De Vries in his study of the evening primrose noticed inheritable changes which he called mutations. Since he noticed that the evening primrose continued to mutate during his experiments, De Vries suggested that such mutations might pile up over a long period of time; and, if the organisms were able to live and reproduce, there would thus arise forms which were more and more different from the original organism in which the first mutation occurred. Since the periods of geological time are enormously long, many new characters could appear. Entirely new organisms that could be classed as new species could arise by the addition of many small mutations.

Mutations and chromosomal changes have varying effects on organisms. Some mutations or chromosomal changes weaken the organism, so that it soon dies and fails to produce offspring with the new character. Some have little or no effect on the organism's ability to survive. But some changes make the organism more fit to meet the conditions of life and, therefore, to reproduce. Such changes are likely to be passed on to future generations. For example, a wheat plant that, because of a mutation, acquires the ability to resist a disease will live and reproduce when its neighbors that cannot resist the disease have died and failed to reproduce. In the next few generations there will be many wheat plants with the mutation which has proved itself of value to the plant.

Of course, if the germ does not attack the plant, the mutation to resist the disease will not help the wheat plant to survive. And if the ability to resist the disease happens (because of linkage) to be inherited together with a slower rate of development the mutants that are better fitted in one way may be caught by an early frost and killed. In that case the useful mutation will not be transmitted. Changes may have complex effects; it is not easy to say whether or not a change will in the end help to produce a new type of organism. *Exercises 1, 2.*

Charles Robert Darwin. When De Vries attempted to explain the origin of new species through mutations he was building on the work of Charles Robert Darwin, who had done his work almost half a century before. Darwin lived at a time when few fossils had as yet been found and when geologists had just begun to find evidence that the earth had a long history of change. It had been believed by many scientists of earlier days that the earth had always held the kinds of living things that they saw about them. But as more and more fossils were unearthed the study of these fossils showed that many kinds of living things which once inhabited the earth had died out and that many kinds of living things now present on the earth had not always been living here. This called attention to the problem which had been raised by scientists before, the problem of how these many species had originated.

It is interesting to trace the steps by which Darwin arrived at an answer to this question because you will then be able to understand how he succeeded in convincing other scientists. When Darwin was twenty-two years old he took a post as naturalist aboard the "Beagle," a British vessel which was to make a trip around the world. For five years Darwin made observations, recorded them, and collected specimens. He studied rocks and their layers, the formation of coral islands, and the places in which animals and plants lived. He observed, recorded, and collected whether sailing on the high seas or visiting the great deserts of Patagonia, the forest-clad mountains of Tierra del Fuego, the dense jungles of the tropics, and the shores of the Galapagos Islands off the west coast of South America. In the course of the trip Darwin noticed many puzzling facts about plants and animals. But gradually he was able to read some meaning into these observations. By the time he returned to England he believed that plants and animals had changed throughout the ages. He believed that new types had arisen from preceding types, the more complex forms appearing as the descendants of the simpler ones, so that all living things bore a relationship to one another. In other words, he believed that *organic evolution* had taken place.

But Darwin wanted still more evidence and wanted to know how all this might have come about. You must remember that at the time when Darwin was studying the problem the great fossil beds had not been explored. Nothing was known about chromosomes or genes; in fact, when Darwin returned from the voyage of the "Beagle," Schleiden and Schwann had not yet announced the cell theory. The problem was a difficult one for Darwin to solve; for this reason he continued to search for facts and more facts. For another twenty years he kept on collecting facts that would support or disprove his belief. During all this time he made no public mention of his work.

Darwin and Wallace. Before Darwin was ready to present his views to the world, he received a report from Alfred Russel Wallace, who had just finished studying animal life in the East Indies. In this report, Wallace presented the very ideas that Darwin had so long been turning over in his mind but had not yet published: first, that the different species of plants and animals arise by evolution; and second, that evolution takes place by the particular method that Darwin considered most probable, a method which Darwin spoke of as "natural selection."

With characteristic fairness and generosity, Darwin was at first inclined to publish Wallace's report and say nothing about his own conclusions. But friends to whom he mentioned the difficulty insisted that, since he had been working on the problem for twenty years, both he and Wallace should present their reports at the same time. Darwin's generosity was matched by the fine spirit of Wallace, who always gave Darwin credit for having been the first to develop the idea of evolution and for having studied the problem more thoroughly.

What is meant by Darwin's theory of natural selection? It was clear to Darwin, who had studied not only the plants and animals that are found in nature but also domesticated forms, that there was endless variety among the members of a species. Any two organisms of the same species, if studied carefully, proved to be different in many small ways. You know that this is true; you even understand the causes of such variations. Darwin was not well acquainted with the causes of variations because little was known about the matter then. But he did know that no two individuals are ever exactly alike; there is *variation* in living things.

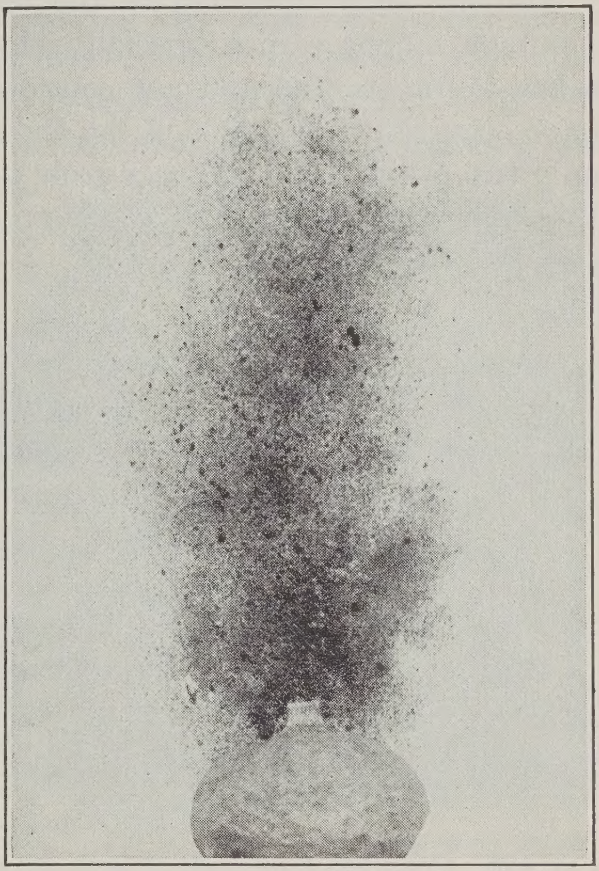


Photo by Cornelia Clarke

FIG. 475. A puffball exploding and discharging spores. It has been calculated that a large puffball may contain 6,000,000,000 spores.

Darwin's studies impressed him with another important fact which is also familiar to you. Most animals and plants produce offspring at so great a rate that if all lived and reproduced there would not be standing room on the earth for the individuals of even one species. If you calculate the descendants of a pair of cats, assuming that they begin to reproduce at the end of the first year and live for ten years, producing one litter of four kittens every year, your figures will soon run into the millions. The total number of descendants after ten generations of a fish like the cod which lays 8,000,000 eggs every year is staggering. And what is true of animals is true of plants. There is *overproduction. Exercise 4.*

You are so accustomed to the idea of reproduction in large numbers, among plants especially, that you have probably always taken it for granted and not considered its results. It may not have occurred to you that if the cod does not increase in number only two of the 8,000,000 eggs grow to maturity, and 7,999,998 of that family die before they can reproduce. A few organisms are increasing in numbers. But the rate of increase is slow. Even among these only a small proportion of the fertilized eggs grow into adults.

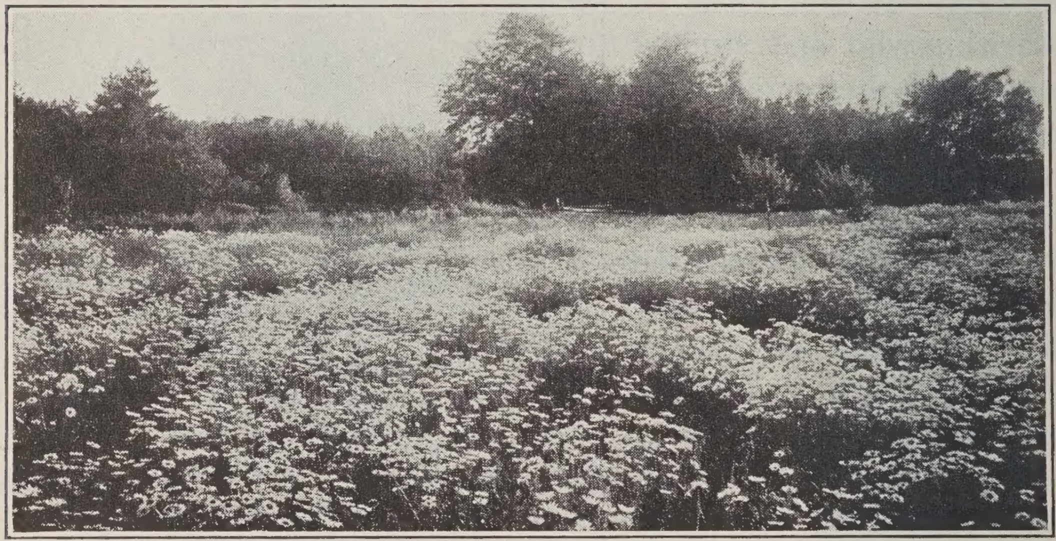


Photo by Mary C. Dickerson, Courtesy Am. Mus. Nat. Hist.

Fig. 476. Countless thousands of seeds fell in this daisy field. In which ways may these daisies have been better fitted for survival than those that failed to grow?

If only two of the offspring live and all the others die, there is, as Darwin pointed out, a *struggle for existence.* The more offspring produced the keener, under ordinary circumstances, is the struggle. You must not think of this struggle as a bloody battle between codfish, or between codfish and other larger animals. The struggle for the necessities of life is, for the most part, a quiet, steady struggle that is difficult to observe. It is a struggle in which large numbers compete and in which more and more plants and animals fall by the wayside until, usually, only two of a species remain to take the places of their two parents.

Since there are always variations among the members of a species, some organisms will be more fit to meet existing conditions, some less fit. In general, the more fit survive, the others die. Darwin pointed out that this should hold true particularly when conditions changed or emergencies arose. In general, the survivors tend to be those organisms that are better fitted than others to meet new situations. This has been called the *survival of the fittest.* Some puffballs or codfish or cats are continually dying off or being killed. Those that survive to the very end are, by and large, the most fit. *Exercises 5, 6.*

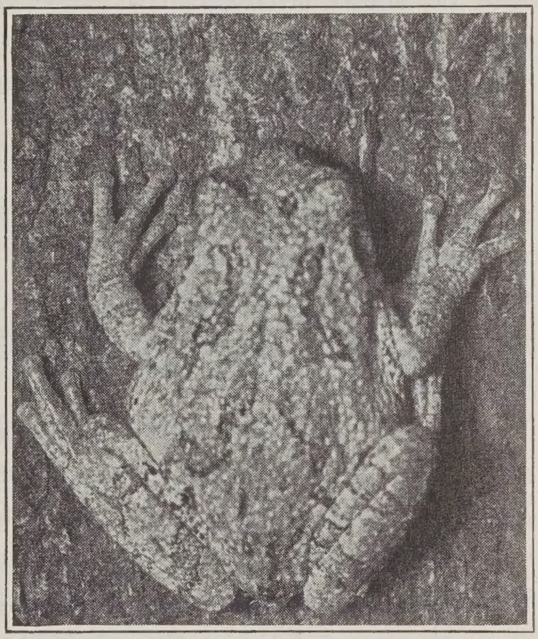


Photo by Frank Gehr

FIG. 477. In what ways is this gray tree frog better fitted to its environment than other frogs would be?

Fitness and survival. It is clear that the word *fittest* does not necessarily mean the strongest. It means the organism that fits into the whole environment best, whatever the environment may be at that particular time. Under some circumstances the fittest might be the largest; under other circumstances, the fittest might be the smallest because the smallest could hide in a tiny crack while the larger form would remain exposed. It might be the animal with the sharpest eyesight; or, if the animal lived in a completely dark cave, it might be the one that developed without eyes but had particularly keen sense organs of some other kind. In one environment, it might be the animal that was dull colored; in an environment of brightly colored flowers, a brilliantly colored animal might be less conspicuous and more fit.

Fitness is much more complicated than the simple examples given above may seem to indicate. The environment is so complex that organisms may be fit in some ways and unfit in others. Desert animals that are dark in color survive even though this coloring makes them conspicuous in the bright sunlight or moonlight of the desert. These organisms must be able to survive because their fitness in other ways counterbalances the lack of protective coloring. Fitness shows itself as cooperation, in many cases. Some animals live together in groups. The males protect the females and the young. In other cases, as you have read, there is a social organization, as in the ant nest or beehive.

Fitness is shown by simple plants and animals as well as by the complex. The lowly ameba and seaweed, although they have been less changed through the ages than the organisms that became man or the orchid, are adapted as are the higher organisms. Fitness is thus a quality of all the plants and animals that are not dying out.

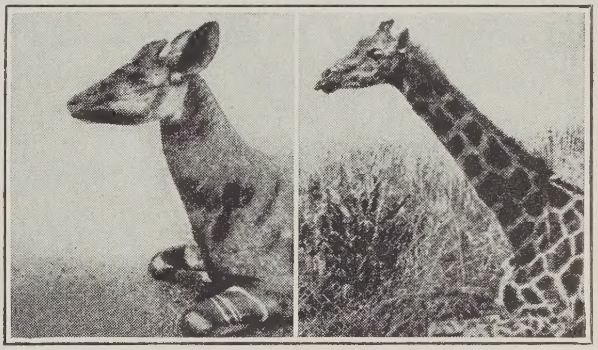
Often, fitness does not help the organism at all. A cloudburst in a small area may destroy all the plants; the more fit will be killed with the less fit because none of them can resist the heavy rain. Chance evidently plays a part in determining which organisms will survive. But, in general, survival is determined largely by fitness. *Exercise 7.*

Natural selection and the origin of species. Natural selection acts as a great sieve or strainer for sifting out and preserving those organisms that are more fit because of some variation. If a variation is one that can be passed on to the offspring, a few of the individuals of the next generation will start life better fitted than the other members of the species. At first there will be only a few. But as more and more individuals inherit the variation which increases their fitness, they will crowd the others out. If the struggle for existence should become severe, all the less fit may disappear. In this way, after many generations of sifting out and preserving useful variations, natural selection probably changed the tiny Eohippus into the modern horse.

However, Eohippus could never have changed into the horse through natural selection unless there were *inheritance of variations.* Natural selection can account for the origin of new species only if the variation that made an individual more fit was one that could be passed on to the offspring.

Darwin lived too early to know that mutations and other chromosomal changes take place and that they can produce inheritable changes in organisms. He was therefore unable to explain clearly how some variations are inherited and others not. He was aware of the weaknesses in his own theory of natural selection and stated them frankly so that other biologists might study them. He knew that his understanding of the problem was far from complete.

Sometime after Darwin presented his theory, Weismann helped to clear up the difficulty by making a distinction between germinal variations (those that are inherited because they are changes in the germplasm) and somatic variations (those that do not affect the offspring because they occur in the body cells only). Later when De Vries found that certain variations can be inherited, those that he called mutations, he fitted this idea into Darwin's earlier theory. According to De Vries there is a struggle for existence because most organisms tend to reproduce in enormous numbers. When a mutation occurs which makes the organism more fit than others of its species, this mutant will tend to survive. Since the mutation can be inherited the desirable change will continue. Thus, after long periods of time, entirely different or new species become established.



Courtesy Am. Mus. Nat. Hist.

FIG. 478. The okapi (left) lives in forests where it can feed on the lower branches of trees. The giraffe lives on the plains where it feeds on the higher branches. How would De Vries have explained the origin of the giraffe?

In this form the theory of natural selection is acceptable to most biologists. There are differences of opinion among biologists about many of the details of natural selection and even about the importance of the various factors that Darwin listed; nevertheless, the origin of species by natural selection represents the most satisfactory explanation today. *Exercise 8.*

There are a few biologists who believe that the Chevalier de Lamarck, far back in 1809, offered an explanation of the origin of species which at some time may still prove to be correct. Lamarck suggested that the amount of use that an organ received and the way in which it was used would produce a change in the organ, and that this change could be inherited. Lamarck said that each change would be small, but over long periods of time, if small changes heaped up, new forms would appear. If Weismann was correct in stating that acquired characters cannot be inherited, Lamarck's theory cannot be accepted. While biologists are still performing experiments to determine whether an acquired character can ever be inherited under any circumstances, most biologists believe that there is no evidence for it. Lacking the proof that acquired characters can be inherited, Lamarck's theory is not satisfactory.

Naturally, it is far more difficult to determine *how* new species of animals and plants originated throughout the ages than *that* they did originate by arising from other species before them. The biologist can only assume that what happens in his experiments can have happened in the past. Thus he remains in some doubt about the method by which species originated. *Exercises 9, 10, 11.*

Exercises

1. List certain types of changes in the corn plant and the deer (or other organism) that would weaken them.

2. What kinds of changes in corn plants and deer might make it easier for them to meet the competition of other organisms?

3. Recall three different types of variation in organisms. (See Unit XIII.) Describe them.

4. Prepare a list of your own observations of overproduction of organisms. Compare it with the lists prepared by your classmates.

5. How does a battle between two buck deer, in which one may die, differ from the struggle for existence of which Darwin wrote?

6. Name in order the three steps of natural selection, and explain each. What other kind of "selection" is there besides natural selection?

7. Look back over Parts 1 and 2 of this book to find ways in which organisms are fitted to survive. You and your classmates might prepare a long list by putting together what you have found.

8. The chief ideas that make up Darwin's theory of evolution may be listed as numbered statements. Write your own list and compare it with the lists prepared by your classmates. If there are differences discussion and rereading of the text will remove them.

9. In what ways did Darwin show attitudes of a scientist?

10. Can you explain the difference between evolution and a theory of the way in which evolution took place?

11. *Summary.* Can you describe the theory that is based on the work of Darwin and De Vries? If you can, you understand this section. Write your explanation in your own words. How does Lamarck's theory differ from your explanation?

Activities for the Junior Biologist

1. Prepare a short talk on De Vries's life and work. Deliver it to the class.

2. The story of Darwin's life is fascinating because he never lost his courage in the face of a life-long illness. Prepare a report on the way he worked. You will find the *Life and Letters of Charles Darwin*, by his son, interesting.

3. Find out how Wallace arrived at the idea of organic evolution.

4. Overproduction of organisms is illustrated in a simple way in a jar containing molasses, water, and a very little yeast. Compare the numbers of yeast plants every hour or two by removing a small drop of the liquid and examining it under the high power. What happens finally? Why? You can perform the same sort of experiment with a one-celled animal, such as Paramecium. Keep careful records of temperatures, light, etc.

5. The plants of the cabbage family provide an interesting example of variation. Study red and white cabbage, kohlrabi, cauliflower, brussels sprouts, and broccoli. Describe the differences. If you can grow plants in your backyard, hybridize two of these. Prepare a report.

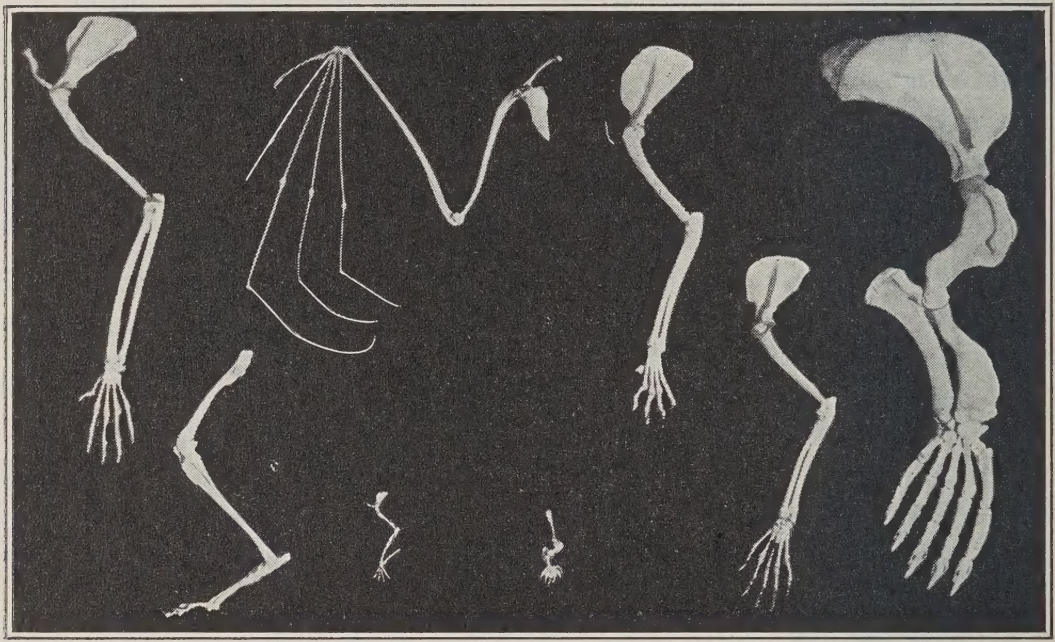
6. If you keep Drosophila in your school laboratory or at home you can test the theory of the inheritance of acquired characters. Remove a wing or both wings. Keep this up for as many generations as possible. Or keep Drosophila in darkness to find out whether they will still respond to light. What will be your control?

7. You can see the results of evolution in the many species of such genera as *Viola* (the violets), *Aster*, *Solidago* (the goldenrods), and *Ranunculus* (the buttercups). If you live where there are fields and woods collect specimens of these groups and arrange them to show similarities and differences.

4. An Understanding of the Origin of Species Has Made It Possible to Explain Many Puzzling Biological Facts

Resemblances in structure can now be explained. Many years ago biologists noted, what you saw in Unit X, that there was a marked resemblance in the skeletons of all vertebrates. It puzzled them that animals as different in their outward appearance and in their way of life as the bird and the cat, the whale and man, should be so similar in their bony framework. Since organs such as the leg of the cat, the wing of the bird, the flipper of the whale, and the hand of man are used for such different purposes it seemed strange that they should be built on the same plan. These facts remained puzzling until it became clear to scientists that each type of vertebrate arose from some earlier type which, in turn, came from an even earlier form, and so on back to a common ancestor. Biologists then understood that vertebrates were alike because they had come from a common ancestor.

The resemblances in systems other than the skeletal system can be accounted for in the same way. If vertebrates are related one would expect them to show many similarities. A close comparative study of an organ, such as the brain, shows, as you have noted before, that the brains of the vertebrates can be arranged in a series according to their resemblances. The brain of the amphibian is most like that of the fish, the reptile brain is less like the brain of the fish, the bird brain is still less similar, and the mammalian brain is least like it. Yet, if you compared the brain of the fish at one end of the series with that of the mammal at the other end, the similarities might not be noticed. Why is that the case? The answer can again be found in a study of the fossil history of



Courtesy Ward's Natural Science Establishment

FIG. 479. Front appendage of monkey, bat, cat, seal (top row); rabbit, flying squirrel, mole, raccoon. What similarities do you note? In which region do you note the greatest differences? Can you explain how these similarities and differences arose during the Age of Mammals?

these organisms. The amphibia seem to have appeared on the earth soon after the fish. Before the reptiles appeared many more ages had passed and many more mutations had occurred in all the organs, including the brain; before the mammals appeared there had been time for other and even greater changes. Thus the vertebrates that are the most distantly related are the most different in structure. In their embryonic development the different types of vertebrates show the same kind of similarities and differences. (See Unit X.) *Exercise 1.*

The classification of organisms takes on new meaning. You read in an earlier part of this book that many years ago Carolus Linnaeus classified plants and animals according to their resemblances. This scheme of classification put together in the same species the organisms that were most alike. Similar species were put together into the same genus; similar genera into the same order, and so on to the phylum, which is the largest group within the kingdom.

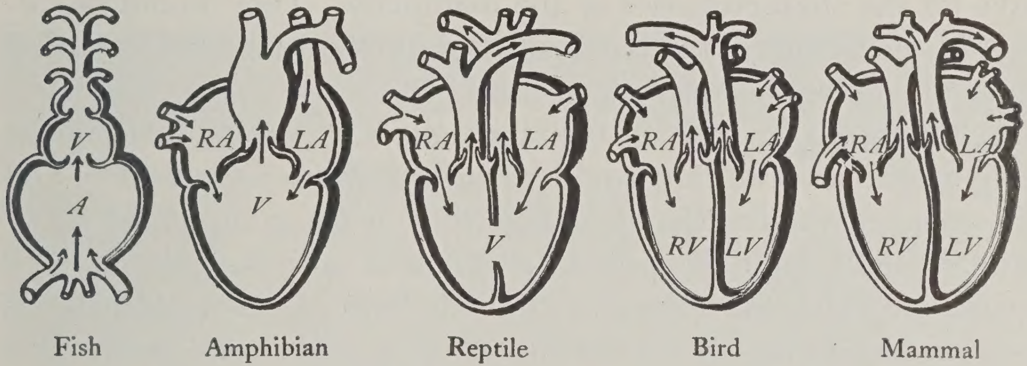


FIG. 480. Compare the lower part of the heart in the last four forms. Compare the auricles. Which heart is least like the heart of the mammal? Which next, and so on?

Linnaeus's classification was successful because, with some changes, it was always possible for the biologist to fit a newly discovered organism into the scheme. At first, it seemed remarkable that all plants and animals should fit so neatly into some genus or order.

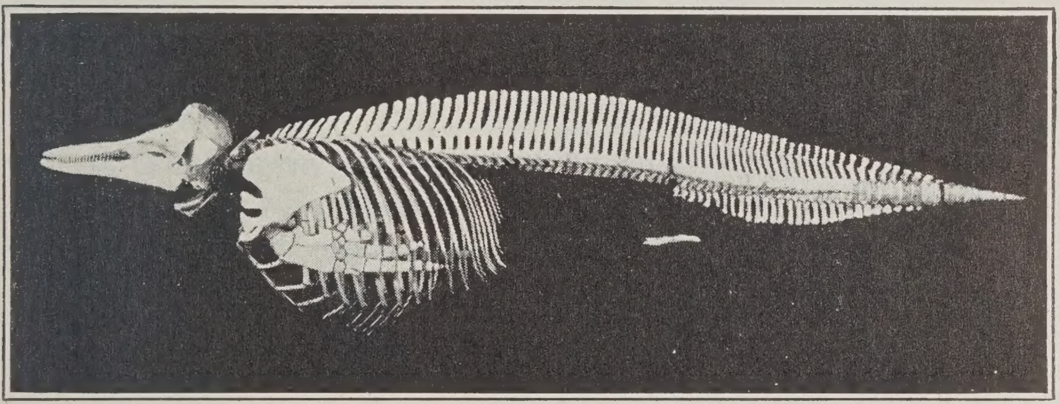
When Darwin presented his reasons for believing that new species arose by descent from preceding species as changes were inherited, he showed that this also explained why all forms arranged themselves into phyla, classes, orders, families, genera, and species.

How this happens may be understood if you consider a possible case. Suppose that in the middle era of earth history a series of mutations occurred that produced organisms with hair instead of scales; organisms that not only bore their young alive, as many reptiles do, but nourished them on milk. Such animals were the primitive mammals. As the ages passed a series of mutations in some of the primitive mammals produced long eye teeth for tearing flesh. At the same time, other mutations in other mammals produced large flat molars for grinding grass. These two kinds of mammals would then be related because they had come from a common ancestor, the primitive mammals that had appeared long before. Both kinds would be much alike because they would still have all the characteristics of the mammals. They would be different because mutations had produced different kinds of teeth and other differences between them.

As time went on, some of the mammals with tearing teeth might have acquired claws that could be withdrawn, long whiskers, and the other characters that you now find in the genus *Felis* (cat). Others might have undergone a different series of changes by mutation. They developed a different kind of claw and a bark; they developed the characteristics of the genus *Canis* (dog). But the cat and the dog would have many characteristics that are similar. They would be rather closely related because they had a common ancestor not so very many ages ago.

Since biologists believe that this has happened to all kinds of animals and plants it is easy to understand why some should be very much alike and others less alike. The whole Linnaean scheme of classification is thus made possible because of the way plants and animals changed throughout the ages. *Exercises 2, 3.*

The presence of useless structures in animals can now be explained. Many animals have parts or structures which seem to have no function and sometimes seem quite out of place. For example, the whale has a number of bones close to the spinal column on either side in that region where in another mammal the hind legs would be attached to the backbone. The whale develops these and carries them through life — wholly useless structures. Until biologists accepted the idea of evolution they had no way of explaining why these structures developed in the whale. When you consider that whales, like all other animals, developed gradually from some other form these "useless" bones take on a meaning. Whales, being mammals, are descended from some mammalian type with four legs. Probably, by accumulated mutations, in which the hind legs and hip bones became smaller, the species known as the whale arose. Living its whole life in the water and with a tail for propelling itself, the animal that was becoming a whale did not use its hind legs. As chance mutations occurred in which the hind legs became smaller and then disappeared, the animals were at no disadvantage in the struggle for existence. The small bones remaining where the hind legs once had been are known as *vestiges* (ves′ti-jes — remnants) or *vestigial* (ves-tij′ee-al) *structures.*



Courtesy Ward's Natural Science Establishment

FIG. 481. Skeleton of porpoise, a relative of the whale, which never leaves the water. What vestigial structure do you see?

There are many vestigial structures in man. One is the appendix, an organ without any known function. The appendix is tiny in man, but large in rabbits and some other mammals in which it acts as a digestive organ. Some people still have scalp and ear muscles which can be used, though to no purpose; in most of you these structures have become vestigial. The bones of the tail (*coccyx*) in man are much reduced in number, a vestige of the tail found in most mammalian forms. A close study of the anatomy of many animals shows structures which seem to be without meaning until one realizes how these animals came to exist. If animals are related to one another more or less closely and if new forms arise from previous ones by the inheritance of many changes, vestigial structures can be explained. *Exercise 4.*

The distribution of animals and plants on this earth. By and large the spread of animals is a slow process that occurs when a few individuals wander off in search of food or shelter and then settle down in another region because conditions are favorable. This slow spreading out of the *ranges* (places in which species live) of organisms has been going on for a long time. Therefore one might expect to find each species fairly well distributed over the areas which are suitable in climate, provide the right food in sufficient amounts, and have not already been occupied by enemies.

In actual fact one does not find this. Many organisms have not done so because there are *barriers* in the way. Barriers may be mountain ranges over which the organisms cannot pass, or great bodies of water like the oceans, or even large deserts like the Sahara and Kalahari in Africa. The choicest of homes and the most plentiful supplies of food may lie just beyond a barrier; an organism often cannot reach them.

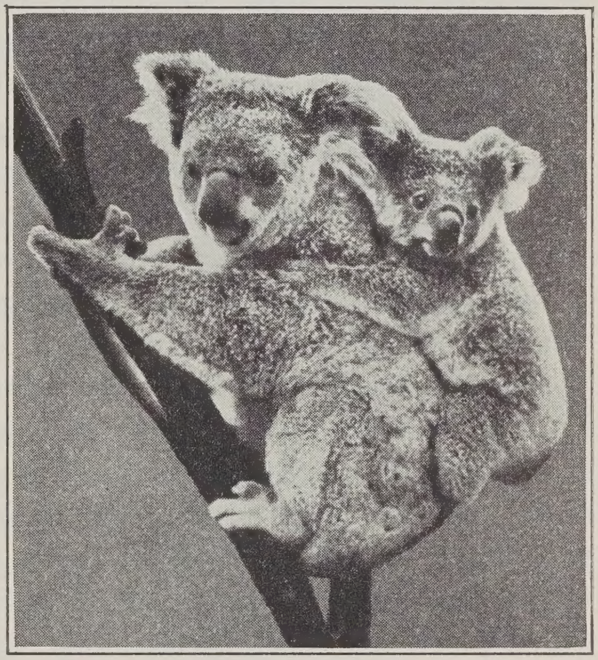
Biologists recognized this fact soon after they began to study the distribution of plants and animals. They found that it explained many of the unusual distributions that were discovered by explorers. But, as they continued their studies, they found that the presence of barriers could not explain all the unusual distributions. In fact, the most unusual distributions seemed to have no reasonable explanation.

Australia provided one puzzling situation. When biologists studied its fauna (animal population) they found a varied group of mammals, many of which looked like the common mammals of other continents. Some of the Australian mammals looked like bears, others like wolves, and so on. But closer examination showed that the Australian mammals were lower mammals, simpler in structure than the mammals of other continents; they were like the kangaroos in having pouches in which their young were kept for a time after birth. Outside of Australia there is only one other pouched mammal, the opossum which is found in the United States and in South America.

This unusual distribution of mammals can be explained by an understanding of how forms changed from simple to more complex throughout the ages. As increasingly more complex animals appeared on this earth, there developed a simple type of mammal which protected its helpless young by carrying them in a pouch.

There was a time in earth history when the only mammals were these pouched mammals (marsupials). By a study of the rocks, geologists discovered that during this era of earth history, Australia was connected to the other continents. The primitive pouched mammals wandered freely about, settling wherever conditions did not destroy them.

But then Australia was cut off from the rest of the world by a barrier, the ocean. The wandering stopped. Ages later, somewhere else in the world, a more advanced type of mammal developed, one that did not carry its young in a pouch. It was better fitted to its environment than the primitive pouched mammals so that in the steady struggle for existence it began to crowd the primitive mammals out of existence. But it did not reach Australia because the ocean now created a barrier around Australia. In Australia, therefore, the pouched mammals met no competitor and continued to live undisturbed. In a still later era of earth history, the pouched mammals in the rest of the world became extinct, leaving only the opossum, which had succeeded in holding its own in the Americas. Of course, the pouched mammals of Australia did not remain unchanged throughout the millions of years that followed. The mutations that occurred changed them outwardly as they had changed some of the higher mammals in the rest of the world; the Australian mammals looked like bears and wolves and so on, but they all kept the pouch in which they carried their young right after birth.



Courtesy Nature Magazine

FIG. 482. An Australian koala, which like the kangaroo carries its young when first born in a pouch.

That it was not climate or food which prevented the development of complex mammals was shown when the white settlers brought rabbits to Australia. In just a few years these had overrun large parts of the continent.

There are other strange facts of animal and plant distribution which can be explained when one considers that living types come from preceding simpler types. The Galapagos Islands are a small group of islands, probably of volcanic origin, lying near the equator about 500 miles west of South America. When Darwin visited the islands during the voyage of the "Beagle" in the first half of the last century he made a careful study of the animals and plants on the island and compared them with the species that lived on the mainland. He was puzzled by the fact that the species living on the islands and those living on the mainland were very much alike although the island environment is very different from that of the mainland. Darwin had expected that the environment would have a more important influence on the plants and animals.

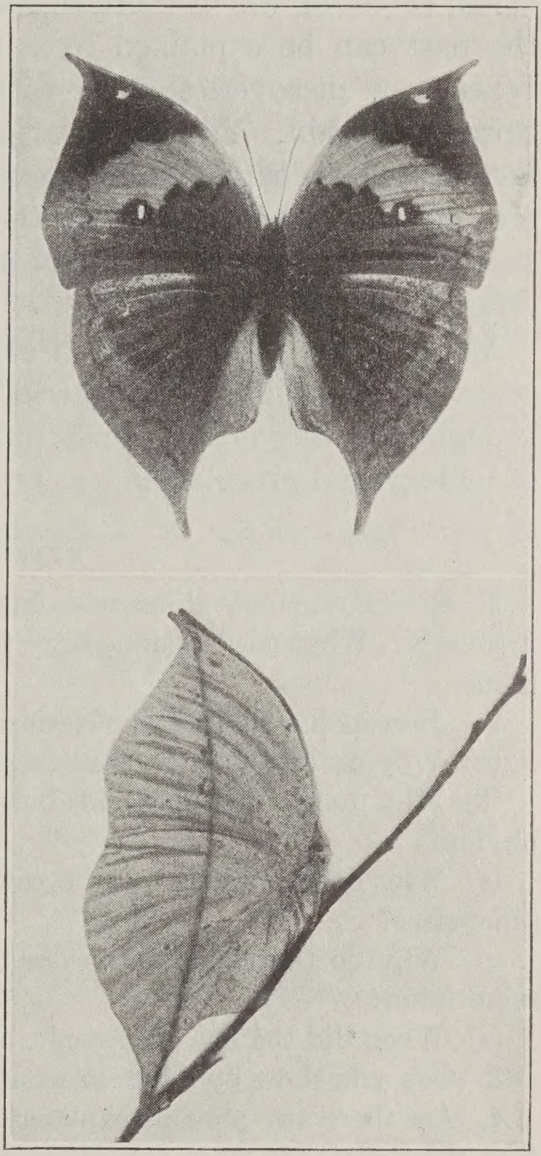
But when he realized that organisms developed slowly throughout the ages from preceding types, Darwin was able to explain the unexpected distribution. Animals and plants were carried to the islands from the mainland by accident. At the time that this happened, the organisms of the islands and of the mainland were alike. As time went on, some changes occurred in the organisms of the islands and other changes in the forms on the mainland; the two groups of organisms thus grew different. Since this has all taken place within comparatively recent geologic time, and there has not been time for a large accumulation of mutations, the two sets of organisms still show many similarities.

There are many examples of unusual geographic distribution; in most cases they can be explained by applying the idea that new types of plants and animals have developed from older types, the new types being more complex than their ancestors. *Exercise 5.*

Extraordinary adaptations of organisms to their environment. You have seen, or read of, the astonishing instincts and adaptations of some organisms to their environment. Protective coloration among birds, and insects which look like twigs are well known examples. There are innumerable cases of adaptation both in structure and in behavior. See Figs. 325 and 326.

Biologists have collected many hundreds of examples of useful adaptations. Before the origin of species was explained, no one could supply a satisfactory explanation for the presence of such structures and such seemingly intelligent behavior. Now, many of these extraordinary adaptations can be explained by natural selection.

Since mutations may change an organism in any direction, there are individuals that are slightly better fitted and others that are somewhat less well fitted to the environment. Over long periods of time, many inherited changes may occur; in the struggle for existence those will remain which make it possible for the favored individual to reproduce. Thus, the most amazing adaptations may develop simply because the organisms in which they appear are better fitted to survive and pass the change on to their offspring. Of course those heritable changes that make the organism unfit would disappear, because the individuals would die. The biologist, looking around him today, sees only the successful changes, the adaptations that seem so extraordinary. Despite the reasonableness of this explanation in many cases there are some adaptations that have not yet been explained. *Exercise 6.*



Courtesy Am. Mus. Nat. Hist.

FIG. 483. The Kallima or leaf butterfly of India. The upper surface of the wings is brilliantly colored; the lower surface is a grayish brown.

How science checks on a theory. According to the theory of evolution the many kinds of animals and plants appeared gradually on this earth; each kind descended from some earlier form. Of course there is no direct proof for anything that happened in the past, and which goes on so slowly that it cannot be watched.

You may wonder how a scientist checks on a theory for which there can be no definite experimental proof. The best way is to find out whether the theory "works" under all circumstances. When facts for which there seemed no reasonable explanation in the past can be explained by a theory, the theory is accepted. When new discoveries fit in with the theory, its correctness is "proved" again. You have learned that many puzzling biological facts have been explained by the theory that all types of organisms arose from preceding types by the inheritance of changes. Thus, the theory of evolution has become acceptable to biologists and others. *Exercise 7.*

Much of the recent work in genetics helps to explain by what processes evolution can be carried on. The idea of evolution has brought together many widely different facts from the whole field of biology and given them a new meaning. *Exercises 8, 9.*

Exercises

1. Review the facts about resemblances in structure that are presented in Unit X. What new meaning have they been given by your study of this unit?

2. Reread the chapter on classification in Part 1.

(*a*) Why do insects and vertebrates belong to different phyla?

(*b*) Why do fish and mammals belong to different classes but the same phylum?

(*c*) Why do the horse and the cat belong to different orders but the same class?

(*d*) Why do the cat and the dog belong to different genera but the same family?

(*e*) When did the one group split off from the other in *a*? *b*? *c*? *d*?

3. Can you show by diagram what you learned in Exercise 2?

4. Are there any possible explanations of vestigial remains, other than that they were left when forms changed? Discuss the possibilities with your classmates.

5. What effect have modern means of transportation had on the distribution of organisms on the earth? Give details.

6. Why do not all organisms show extraordinary adaptations?

7. Name some controlled experiments that have proved some important biological facts.

8. *Summary.* If you can list the puzzling biological facts that evolution explains and tell how each is explained, you understand what you have just read. Do this.

9. *Unit Summary.* This unit has presented a great many important ideas. To summarize it, prepare an outline to explain each of the four sections of this unit. When you put these together you will be able to explain the unit idea.

Activities for the Junior Biologist

1. By using college textbooks, find other examples of resemblances in structure between vertebrates. Prepare a report. There are cases of resemblances among the invertebrates. Perhaps you can find some.

2. There are many examples of vestigial organs in man. Prepare a large outline of a man's body and mark the places in which they appear.

3. Draw a large map to show the distribution of certain types of plants and animals. Which organisms will you choose? Why?

4. The distributions of some of the animals on this continent illustrate how barriers have influenced the spread of organisms and how new varieties may arise. Read about some of the cases and report to the class.

5. If you are interested in the methods of science, read *What Is Science?* by Campbell.

Good Books to Read

Bradley, J. H., *Parade of the Living.* Coward-McCann.
Crampton, H. E., *Coming and Evolution of Life.* Univ. Society.
De Kruif, P. H., *Hunger Fighters.* Harcourt, Brace.
Fasten, N., *Origin through Evolution.* Knopf.
Huxley, J., *Evolution Up-to-Date.* Harpers.
Locy, W. A., *Biology and Its Makers.* Holt.
Loomis, F. B., *Evolution of the Horse.* Marshall Jones.
Mather, K. F., *Old Mother Earth.* Harvard University. *Sons of the Earth.* Norton.
Matthew, W. D. and Chubb, S. H., *Evolution of the Horse.* American Museum of Natural History.
Merriam, J. C., *The Living Past.* Scribner.
Newman, H. H., *The Gist of Evolution.* Macmillan.
Peattie, D. C., *A Child's Story of the World.* Simon and Schuster.
Ward, H., *Evolution for John Doe.* Bobbs-Merrill.
Ward, C. H., *Charles Darwin.* Bobbs-Merrill.
Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.
Wilson, G., *Great Men of Science.* Garden City Publishing Co.
U. S. Government, Numerous publications. Superintendent of Documents, Price Lists.

UNIT XV. THE FUTURE OF MANKIND IS RICH WITH POSSIBILITIES OF BETTERMENT

1. Man Has Been Long in the Making
2. Science Points the Way toward Human Improvement

1. Man Has Been Long in the Making

Obtaining information about men who lived before historic times. The ages before man kept written records are called *prehistoric* (before the beginning of history). The men who lived then are referred to as prehistoric men. Since there are no written records it is far from easy to discover how such men lived, what they did, and what they believed. But it is not impossible, for there are several kinds of information the scientist can use.

Much of this information comes from the tools and weapons found deposited in the earth. These and the other articles made by prehistoric man are called *artifacts* (are′ti-facts). Some artifacts are extremely simple, mere pieces of chipped flint; others are more complicated, axes of polished stone, bone needles, and later copper or bronze axes. It is not hard to decide that the men who used metals were more advanced than those who made polished stone axes. These, in turn, were more skilled than the men who used tools of chipped flint.

The refuse (garbage) heaps that ancient man left give much information, too. Some heaps indicate what food he ate. For example, huge mounds of shells are found on the western coast; they show that oysters and similar sea food were part of the diet. Some older refuse heaps are important because they show that fire was used; charred bones suggest that meat was roasted. Some, through their size, indicate how many persons lived together, or, sometimes, how long they lived there. When burial mounds or caves containing bones are found, the scientist is sometimes able to make reasonable guesses about the beliefs of such prehistoric men. For example, the care with which the dead are wrapped and the presence of tools indicate that these people believed there was another life after death.

Of course, excellent sources of information are the actual fossilized remains of prehistoric man. These tell the scientist what man looked like, how he walked, and how big a brain he had. But, unfortunately, there are few such remains of early man. Human bones do not last long in the soil and, apparently, men did not often die where preservation could take place.

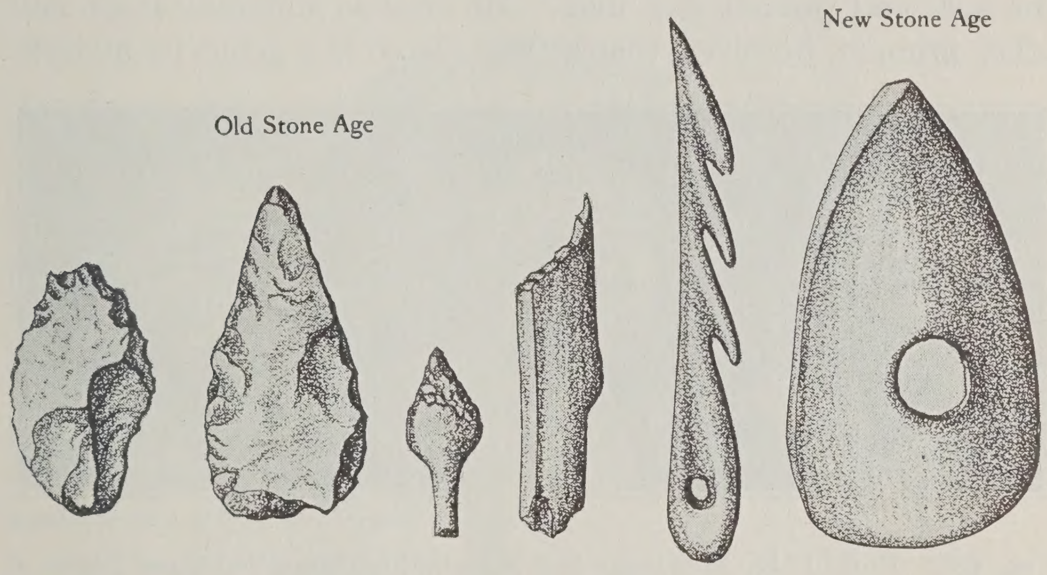


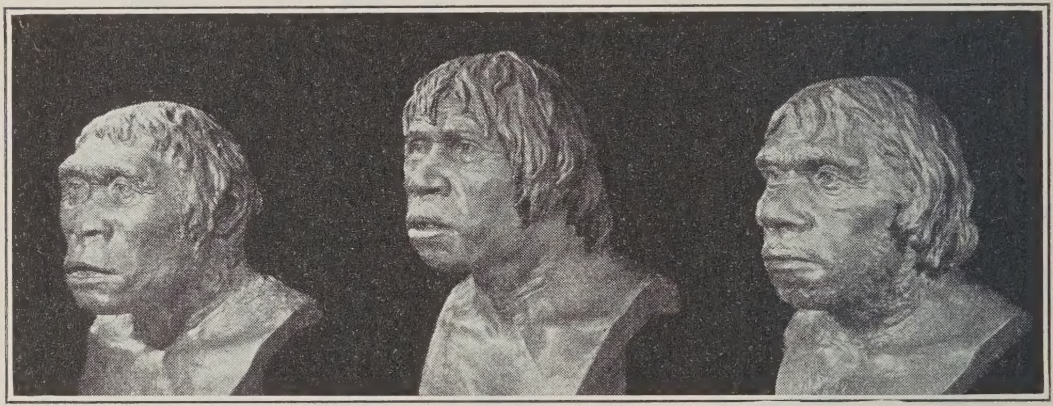
FIG. 484. Old Stone Age and New Stone Age artifacts. How were the later implements an improvement on the earlier?

The greatest difficulty that scientists meet when studying prehistoric man arises from the fact that artifacts and other remains are so recent that they are almost always found in soil and not in rock. In most cases, this makes it difficult to decide the age of the fossil. But there is enough information to indicate that the story of man's making is a long one, stretching back perhaps as much as a million years. *Exercises 1, 2.*

The Java man. When the remains of fossil man and of manlike forms are arranged in order of likeness to modern man, the Java man is perhaps furthest removed. Unfortunately, very little is known about him because only a left thigh bone, the top of a skull, and three teeth have been found. They were dug out of the bank of a stream in the island of Java near the end of the last century.

These bones tell an interesting story. Between half a million and a million years ago, at a time when Java was connected with Asia, there lived a manlike organism that stood about five and a half feet high and that, judging from the shape of the thigh bone, walked erect. His skull shows that he had a much larger brain than that of any ape. But his forehead was flattened and there was a large ridge over the eyes; it is believed that he had no chin and had large, heavy jaws. However, his teeth were much like human teeth in structure.

The Java man belongs to the order Primates which includes the apes and present day man. He was so different from any other primate, however, that he was placed in a genus by himself. He is known as *Pithecanthropus* (pith′eh-can-thro′pus) *erectus*, which means the ape-man that stood erect.

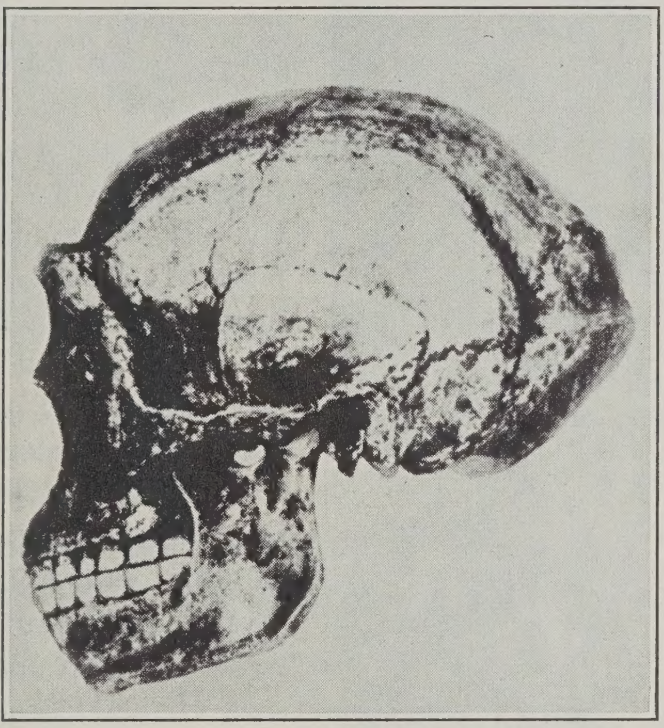


Courtesy American Museum of Natural History

FIG. 485. Prof. J. H. McGregor has painstakingly modeled these heads of Java, Piltdown and Neanderthal man, using the few bones that are available. How did these ancient men differ in structure?

Other early manlike primates. Perhaps during the same period in which the Java man lived in the East, perhaps somewhat later, the Piltdown man lived in Europe. During a time when the glaciers had receded northward he must have moved from the continent into England; in those days there was a land bridge to the British Isles. Little is known about him for only small pieces of two skulls, a part of a jaw bone, and some teeth have been found. The skulls are very much like modern man's; the jaw and teeth are much like a chimpanzee's. Piltdown man has been named *Eoanthropus Dawsoni* (ee′oh-an-thro′pus).

Another manlike type lived in this period or perhaps even earlier. He roamed the hills of Sin (China), living in caves in which his bones have been found. Charred and broken animal skeletons show that he knew the use of fire and may indicate that he killed prey, although many of the skeletons seem to be of animals that came in of their own accord. So many fossils have been found that scientists are fairly sure that they know how he looked. His projecting eye ridges made him resemble the Java man somewhat but his jaws were like those of the Piltdown man. Since the remains were found near Peking he is called Peking man (*Sinanthropus Pekinensis* — sin-an-thro′pus). Recent evidence indicates that Peking man may be even older than the Java man. The caves are still being studied by scientists.

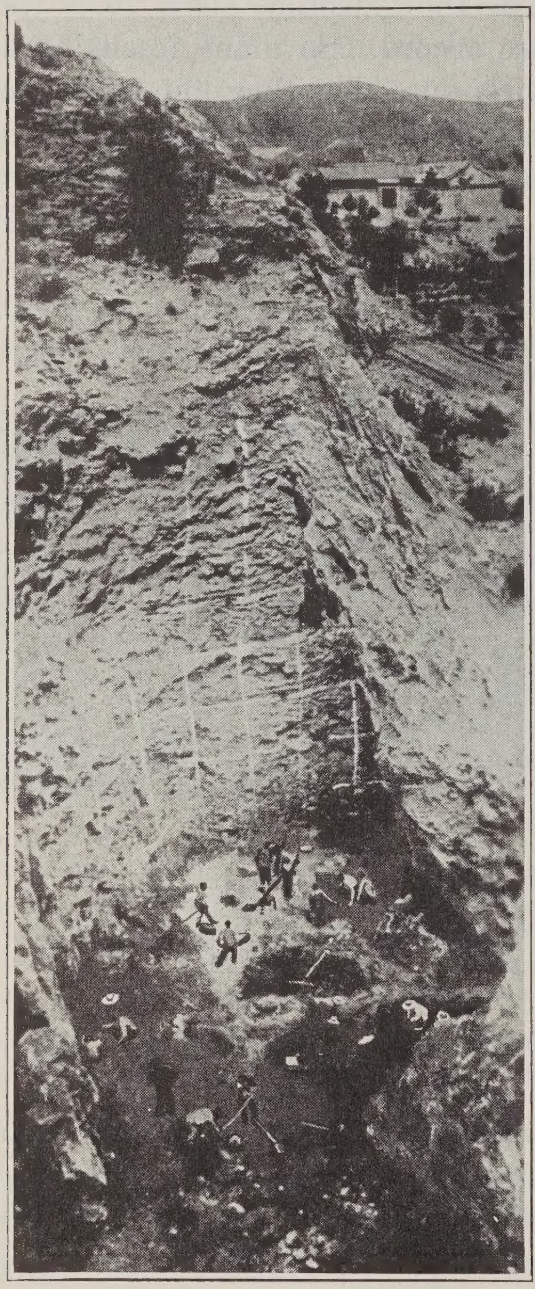


Courtesy Rockefeller Foundation

FIG. 486. Skull of Peking man. Note the heavy eye ridges and lack of chin.

Another early manlike organism is known only by one very large lower jaw, found near Heidelberg in Germany. Although the jaw had no chin the teeth are so modern in structure that Heidelberg man is actually classified in the same genus with modern man, the genus *Homo*. (His name is *Homo Heidelbergensis*.) This form is believed to be more recent than the other primitive forms.

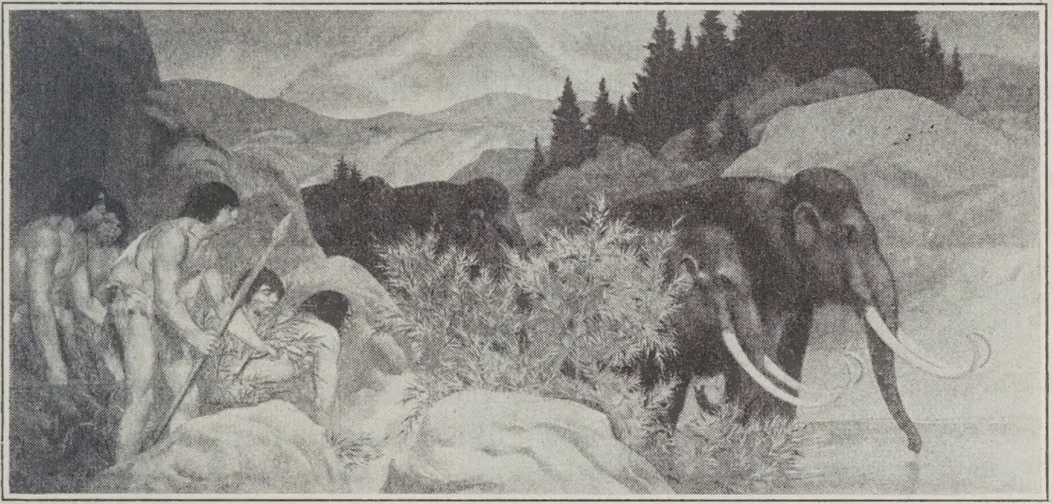
Neanderthal man. Neanderthal man (nee-an′der-tall — *Homo Neanderthalensis*) came much later than the forms you have read about. Unlike them, he is known from many fossil bones, some of which form complete skeletons. The picture that scientists have created is, therefore, much more accurate and complete. Unquestionably, Neanderthal man was a "man" who can be placed in the genus *Homo*, although his low forehead, projecting eye ridges, heavy jaws, and prominent nose separating small eyes must have given him an appearance very different from that of modern man. Though he rarely reached a height of more than five and a half feet he had a broad frame with large muscles, a big head, and short arms and legs. His knees were bent a little so that he must have walked with a shuffling gait, and he stooped at the shoulders. His brain was large in proportion to his size. He had learned to fashion various tools. Scrapers were used, probably for taking meat off the bones and for dressing skins to be used as protection against the cold. For a long time Neanderthal man seems to have met the conditions of his environment successfully even under difficulties as great as those which the Eskimo finds. He must have held his own for thousands of years, during which time he spread through many parts of Europe. But eventually he became extinct, crowded out, it is believed, by another species of man. *Exercise 3.*



Courtesy Rockefeller Foundation

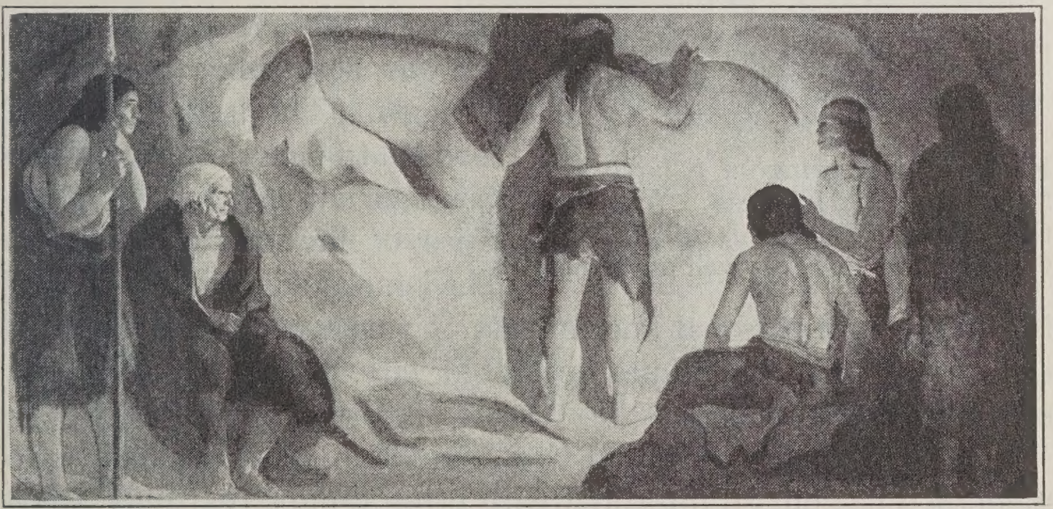
FIG. 487. Excavating for Peking man near Peiping (Peking), China. Why are the squares drawn on the side?

***Homo sapiens* appears on the scene.** About 25,000 years ago while Europe was again largely covered with retreating ice fields the continent seems to have been invaded by the strong and vigorous Cro-Magnon man. These men were so much like modern man in their structure that they are placed not only in the same genus but in the same species. Like you, they belonged to the species *Homo sapiens*. Cro-Magnon man was about six feet tall and well proportioned, with regular features. His brain was large, larger than that of modern man.



Courtesy Logan Museum, Beloit College

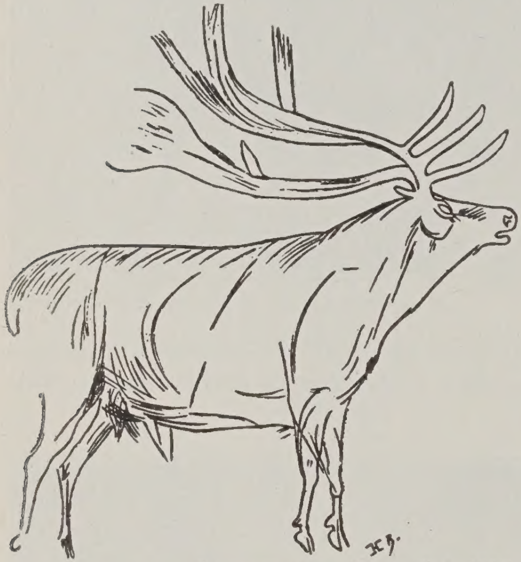
FIG. 488. Some scientists believe that toward the end of Neanderthal man's development he used spears tipped with flint. He was probably not so well formed as this artist has shown him.



Courtesy Logan Museum, Beloit College

FIG. 489. A Cro-Magnon man sculpturing in a cave.

It is known that when the glaciers came down from the north, Cro-Magnon man sought shelter from the intense cold, living in the entrances to caves. He seems to have learned how to obtain light, for there is reason to believe that he sometimes used lamps in the caves. It is possible that he had learned to cook his meat by dropping heated stones into water. Instead of using pots he may have hollowed the earth and lined this depression with skins. Like the earlier species he knew how to make weapons and tools of chipped flint but he discovered a new material which lent itself to tools of a different kind. Bone and ivory now came into use. Thus Cro-Magnon man could fashion arrowheads and sharper spears, and pointed instruments like awls and large sewing needles. Skins were sewed and substantial clothing worn. He was an expert hunter and fisherman, so that food must have been more plentiful in spite of the arctic conditions against which he was sometimes obliged to struggle. The large supply of food led to more leisure. There was time not only for the necessities of life but for luxuries. The bone and ivory were shaped into beads and personal adornments of various sorts. The walls of his caves were sometimes decorated with lifelike paintings and sculptures of animals.

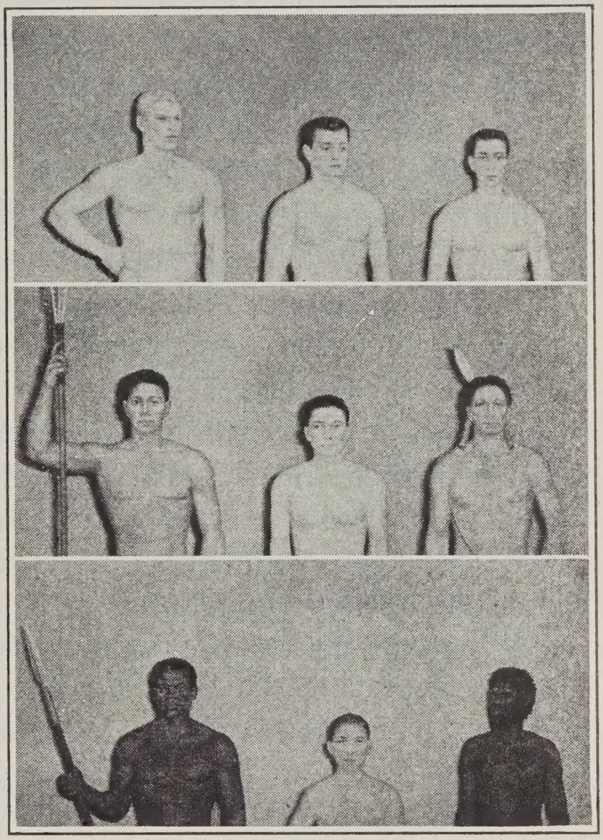


Courtesy Am. Mus. Nat. Hist.

FIG. 490. Drawing of a large stag found in a cave in Spain. Why does the scientist consider this evidence that Cro-Magnon man was well advanced?

Some scientists believe that Cro-Magnon man has come down to modern times but so interbred with other groups that only a few faint, doubtful features can be identified in some of the inhabitants of Europe. *Exercise 4.*

All living men belong to one species, *Homo sapiens*. There are many peoples living on the earth today. Yet all of them, the white, the yellow, and the black, different as they may appear, belong to the same species, *Homo sapiens.* The idea that there may be strikingly different varieties within a species is not new to you. You have learned that the biologist classifies the Boston bull and the Russian Wolfhound within the same species. And you know that the more closely you study organisms and the more familiar you are with their appearance and habits, the more striking do their differences seem. A Chinaman and an Englishman seem vastly different; you readily see differences in build, in color of skin, shape of eyes, and texture of hair. Actually, in spite of the differences that you note, the physical resemblances are great. In all essential structures the Chinaman and Englishman are so much alike that only an expert could tell them apart. If internal structures such as bones and other organs are compared even the expert might not be able to state which was which. All human beings are members of the same species.



Courtesy Dr. H. L. Shapiro, Am. Mus. Nat. Hist.

FIG. 491. By making use of thousands of measurements, Dr. H. L. Shapiro of the American Museum of Natural History has been able to construct figures illustrating some of the races of the three great stocks of mankind. Comparative heights are shown as well as color and general appearance. At the top is the Caucasian stock: the Nordic, Alpine, and Mediterranean races. The Mongoloid stock is next: the Polynesian, Mongol, and American Indian. At the bottom is the Negroid stock: the African Forest Negro, the Bushman, and the Australian.

How man divides his own species into groups. There are so many different kinds of men in the species *Homo sapiens* that it has been found convenient to divide the species into subdivisions. Many scientists speak of three main subdivisions (stocks): the Caucasian (caw-kay′shan) or white, the Negroid or black, and the Mongoloid or yellow. Each group (stock) consists of several races; that is, there are several white races, several black races, and several yellow races.* The races belonging to the Caucasian stock are the Nordic, Alpine, Mediterranean, and Hindu. The Mongoloid, according to this classification, includes the American Indians as well as the Mongolians (Chinese).

This classification into races is, of course, an artificial one. It has been difficult to decide what to use as a basis for classification. Skin color, character of hair, shape of head, shape of nose, and various other characters have been used in classifying men. But in the case of every character the various races grade into one another. For example, there are members of the Mongoloid races that are lighter in color than some members of the Caucasian races; and so with each character.

An important fact about the races of man is that there is no relation between races and national boundaries. France contains members of all three of the Caucasian races; so do Germany and other European countries. Even the Scandinavian countries, which are always thought of as Nordic in composition, contain many individuals who are, on the whole, representatives of other races.

RACIAL CLASSIFICATION OF MAN †

STOCKS AND RACES	TEXTURE OF HAIR ON HEAD	HEAD	STATURE
Caucasian ("White")			
Nordic	Wavy	Narrow	Tall
Alpine	Wavy	Broad	Above aver.
Mediterranean	Wavy	Narrow	Medium
Hindu	Wavy	Narrow	Above aver.
Mongoloid ("Yellow")			
Mongolian	Straight	Broad	Below aver.
Malaysian	Straight	Broad	Below aver.
American Indian	Straight	Variable	Tall to med.
Negroid ("Black")			
Negro	Woolly	Narrow	Tall
Melanesian	Woolly	Narrow	Medium
Dwarf Black	Woolly	Broad	Very short
Of Doubtful Classification			
Polynesian	Wavy	Variable	Tall
Australian	Wavy	Narrow	Above aver.

---

* The few minor races that do not fit into this classification can be disregarded.

† Adapted from Kroeber's *Anthropology*, Harcourt, Brace.

All of these races have helped to develop our modern civilization. At various times in the history of modern man advances have been made by one or another. *Exercise 5.*

Man's civilization has been long in the making. You have learned from the last paragraphs that man developed slowly over a long period of time. But we are interested not so much in the physical development of man and in the races into which we divide ourselves as in the way our civilization has grown up. This can be learned from a study of how the men of each period lived. Scientists have therefore taken great pains to piece together whatever information they could obtain to get a picture of the *cultures* of different groups of men throughout the ages. The word culture is used to describe what people of a particular group do and what they think. To study the culture of prehistoric men one must rely largely on the tools, weapons, and other implements that one finds.

While the cultures of Peking man, Neanderthal man, and Cro-Magnon man were, of course, not the same, they had much in common. It is therefore convenient to describe this whole long period as the *Old Stone Age* (Paleolithic). It was the age when man learned to use stone and fire. It is believed that at first he depended for weapons on sharp pieces of flint which he found. Then he learned to chip the flint; thus he fashioned better weapons and tools. You read of the culture of Neanderthal man; you saw that the culture of Cro-Magnon man was far richer. Yet all these men belong to the Old Stone Age for all were dependent on chipped flint. Cro-Magnon comes in the latter part of this age. He was not entirely dependent on stone; bone, ivory, and shells had come into use. The Old Stone Age lasted for many, many thousands of years, during which there was, for the most part, a slow but gradual advance in culture although at times there was a decline. For example, the highly developed Cro-Magnon art of painting and sculpture seems to have been lost for a time. *Exercises 6, 7.*

The New Stone Age. About 10,000 years ago the New Stone Age began. Man made a great discovery, that of grinding and polishing stone. Such stones could be made into sharp axes for chopping trees. Although the age takes its name from this advance, there was progress along many lines. Simple wooden shelters were constructed; rafts were built; soon the dugout was made. Plants of many kinds seem to have been imported into Europe from Asia. Besides weapons, hoes of polished stone are often found. Agriculture on a small scale must have existed. Useful animals were tamed. The dog was first; then cattle, sheep, pigs, and donkeys were domesticated; horses were tamed later on. Men settled together in groups and undoubtedly had some sort of social organization with headmen of various kinds.

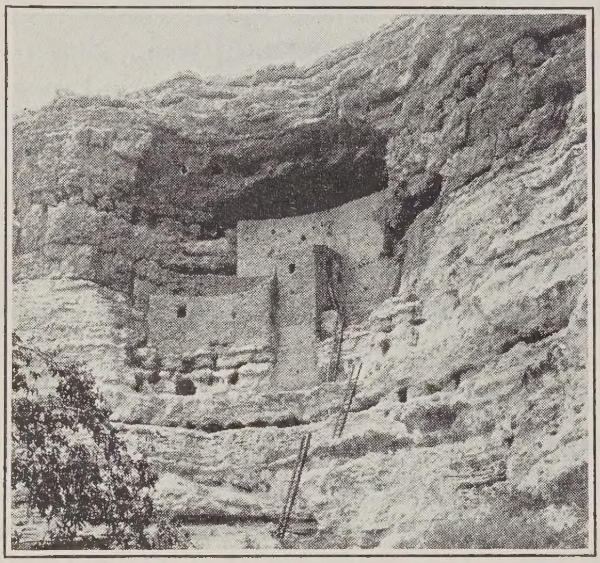


Photo by G. Grant, U. S. Dept. of Int.

Fig. 492. The remains of cliff dwellings a thousand or more years old, in the southwest. The men who lived here were extraordinary builders.

Even before they planted crops, they learned to make pottery; they wove baskets and cloth of various kinds. The remains of villages show that these early men not only buried their dead but engaged in worship of some kind. It is believed that some of them worshiped the sun, for stones are found in lines leading in the direction of the rising sun. *Exercise 8.*

The Age of Bronze. When man discovered copper and learned, perhaps accidentally, to smelt it, man's culture again advanced rapidly. By mixing tin with copper, these early men produced bronze, a harder and more serviceable metal. Thus the New Stone Age gradually developed into the Age of Bronze. This seems to have taken place in Asia about six thousand years ago. Near the Mediterranean Sea there rose the complex cultures of the Egyptians and of other peoples. Language and writing were well developed; men formed into great nations with kings and priests at their head. In their search for copper, for tin, and for gold, which had been discovered long before, the people of this age must have traveled about. This led to the interchange of ideas and goods between different nations, so that civilization advanced rapidly. But in western Europe people were still living in small tribes; metals were not yet in use. Only slowly did the culture of the Near East and the Mediterranean spread through Europe; it became established there at a much later date.

The Age of Iron brings you to modern times. About 3500 years ago the working of iron was discovered. With the widespread use of this metal and the discovery of tempering, by which steel is hardened, modern cultures began. As in the case of other earlier discoveries this step forward was taken in the East, so that again it was long before Europe reached this stage. This brings you to the days of history when writing was generally known and records were regularly kept.

In modern times, since transportation and communication have been so much improved, the cultures of different groups tend to become alike. The more isolated (alone) the group the more does it keep its own distinct culture. For that reason there are still tribes to be found in distant parts of the world whose culture is far different from ours. They happen not to have advanced in culture as rapidly as other groups. But they as well as we belong to one species, man. *Exercises 9, 10, 11.*

Exercises

1. If modern man had no written records what could you learn about him from the objects he makes and uses? Discuss this with your classmates.

2. Learn how the scientist classifies man. See Part 1, Chapter I.

3. Why is it believed that Neanderthal man wore skins? Why is it believed that these skins were not fashioned into real clothes?

4. In what ways was Cro-Magnon man superior to Neanderthal man?

5. What races are represented in your class? How many pupils are descended from more than one racial group?

6. Of what scientific value is it to study the culture of primitive peoples? How may it help to explain the development of early man?

7. How did speech speed up the development of cultures?

8. How did the New Stone Age differ from the Old Stone Age?

9. Why does our present-day culture change more rapidly than did the culture of primitive men?

10. Consult magazines such as the *National Geographic*, the *Scientific Monthly*, and *Natural History* for accounts of primitive tribes. Report on one.

11. *Summary.* If you tell the story of man's development, referring to the fossils and to the cultures, you have mastered this section. How does this section show that the future of mankind is rich with possibilities of betterment?

Activities for the Junior Biologist

1. By the examination of ruins scientists have been able to discover that the Incas and Mayas of this continent had complex religions, a well-developed social organization, and were good scientists. Read up on them and report to the class.

2. Take pictures of pupils who represent the various racial groups. Take pictures of pupils of various nationalities. Do the two sets of pictures parallel one another?

3. What is the racial make-up of the American people? Of what advantage is this in the development of our culture?

4. If you are interested in dramatics, write one-act plays built around the life of early man. Your classmates and you might perform these for the class.

5. If you draw well, paint murals showing the development of man.

6. Various peoples have contributed to modern culture. Divide the class into committees to learn about the culture of the Chinese, the early Egyptians, the Babylonians, and the Greeks.

7. If flint, bone, or even ordinary hard rock can be obtained, try to produce artifacts like those made by primitive man. Are you as successful as he?

2. Science Points the Way toward Human Improvement

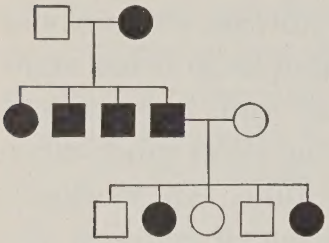
Breeding better men. More than two thousand years ago a nation of ancient Greeks made a practical attempt at breeding better men. The Spartans were interested in conquest; they wanted a large army and strong warriors; by purposely making the conditions of life difficult they helped to wipe out the weaker individuals; the stronger ones survived. Thus in each generation there was a large proportion of strong men. From their own point of view they were successful in breeding better men. But the goal they set themselves was a very simple one and one which many men even of those days could not accept as worth while.

More recently Sir Francis Galton (1822–1911) became interested in the problem of improving the human race. This was before much was known about heredity but Galton knew that for generations men had been improving their plant and animal types. He believed that the human race could be improved too. By taking measurements of large numbers of men and carefully studying these figures he made the first serious attempts at studying human heredity. He laid the foundations of a new science, a subdivision of biology which he called *eugenics* (you-jen′iks), the science of "being well born," or of improving the human race by breeding.

Methods of study used in eugenics. Since mitosis, maturation, fertilization, and development take place in man as in other complex animals, the same laws of segregation and independent assortment of genes must apply to him. But the exact inheritance of any particular character is difficult to determine. In Morgan's laboratory it was relatively easy to discover which genes in the fruit fly were dominant, which recessive, and which incompletely dominant. Carefully controlled experiments could be performed in which large numbers of offspring were examined and counted. This method cannot be used with man. The number of offspring of two parents is always so small that the figures obtained have very little meaning. It takes so long for a generation to grow up that no scientist can observe more than two or three. More important still, experiments cannot be performed. Where there are no controlled experiments, one is never sure which particular factor is responsible for the results. For example, if you were studying the inheritance of size in man you would not be sure of your results unless the individuals studied had had exactly the same environment. This is impossible except under controlled experimental conditions.

The way open to the student of eugenics, therefore, is to investigate the children of hundreds of families and use those facts as best he can. For example, by obtaining figures on eye color it was discovered that when both parents had a certain type of blue eyes their children always had eyes of the same color; brown eyes did not appear in the offspring. On the other hand, brown-eyed parents sometimes had blue-eyed children. By counting the numbers of blue-eyed and brown-eyed children in large numbers of families in which both parents were brown-eyed it was discovered that there was a typical Mendelian ratio of about 3 brown to 1 blue. From these facts the conclusion was drawn that blue is recessive to brown. A method such as this is not altogether exact, however; recently it has been found that some eye colors are produced by the action of several genes.

Another method used is to look up the ancestry or family tree of a given family, and study the inheritance of a certain character through as many generations as possible. A family history of this kind is known as a pedigree. The pedigree can be shown in a chart. In this a male is always shown as a square, a female as a circle. Lines make clear which matings occurred and what offspring were obtained. *Exercise 1* (based on chart).

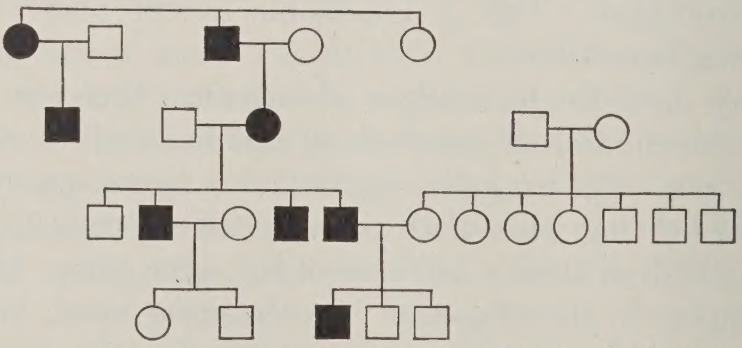


Courtesy L. H. Snyder

FIG. 493. A family pedigree showing the inheritance of one type of extreme shortsightedness. The individual showing the character is represented by a black square or circle. Is the character dominant, recessive, or neither?

Facts of the kind described above may be obtained by personal observation or by sending out blanks containing questions to be answered. The Carnegie Institution of Washington, D. C., has established a Eugenics Record Office at Cold Spring Harbor, N. Y., for this purpose. The Cold Spring Harbor station collects such information, studies it, and then constructs charts showing the inheritance of characters. A British society has established a similar station in London. *Exercise 2.*

This method of collecting information is far from reliable since there is no way of checking on the persons who fill out the blanks. These persons are rarely experts.



Courtesy L. H. Snyder

FIG. 494. This pedigree shows the inheritance of an abnormal skin condition in which the slightest friction causes blisters to form.

What statistics seem to teach about the inheritance of certain physical traits. You have seen that one type of extreme shortsightedness acts as a dominant. The inheritance of more than one hundred unusual conditions of the skin has been studied; of these, eighty seem to be produced by dominant genes and twenty by recessives. Other dominant characters are: the condition of short-fingeredness (brachydactyly), where each finger has only two bones instead of three; and six-fingeredness (polydactyly). Both of these characters appeared as mutations. *Exercise 3.*

A recessive condition that appears again and again is albinism, the absence of pigment from eyes, skin, and hair. Albinos have pink eyes because there is no pigment to hide the color of the blood in the capillaries.

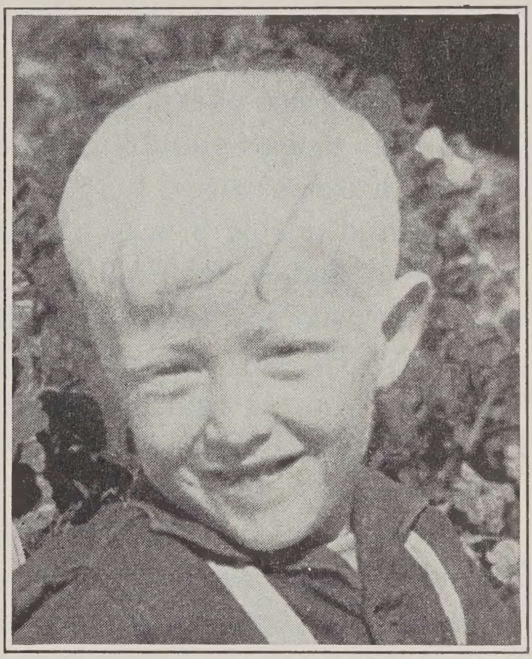

Acme

FIG. 495. An albino child. Do you know why he keeps his eyelids half shut when he is in strong sunlight?

The characters for which inheritance has been most definitely traced are for the most part abnormal ones, bodily defects. These characters are less likely to be influenced by the environment, and they seem to act as simple dominants or recessives. The inheritance of ordinary physical characters, such as general body size, height, weight, skin color, curliness of hair, shape of head and of the features of the face, is more difficult to trace. Apparently these characters are produced not by a single pair of genes but by several or even many genes acting together. For example, height may depend on separate genes — one for length of leg, one for length of trunk, and so on. Also, careful investigation seems to show that in many cases there is blending inheritance.

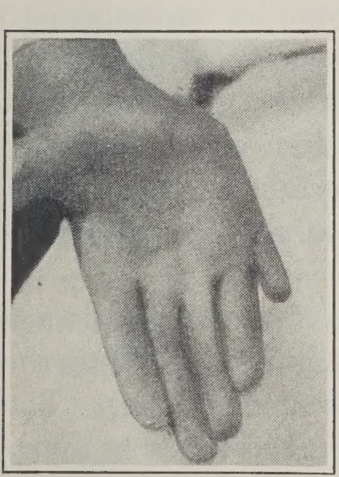

Courtesy L. H. Snyder

FIG. 496. The hand of a six-fingered Negro. In Negroes the extra finger is recessive instead of dominant.

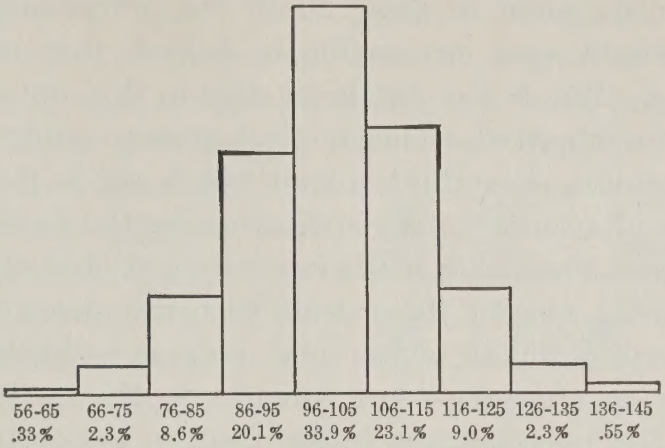
The inheritance of disease has always been an interesting question. You have seen that the inheritance of certain bodily defects has been worked out. There is an unusual disease of the nervous system (Huntington's chorea) which like many other bodily defects is due to a dominant gene. It has been traced through several generations of a Canadian family in which it apparently arose as a mutation. It is a disease appearing in the adult that causes trembling of the upper part of the body. Of course, diseases caused by germs cannot be inherited; they must be acquired during a person's lifetime. However, there is reason to believe that susceptibility to a particular disease is caused by genes, for susceptibility depends on bodily structure and composition. In the case of diphtheria and scarlet fever there is evidence that susceptibility is the result of a recessive gene. Susceptibility to tuberculosis seems also to be inherited, perhaps as a recessive. *Exercise 4.*

Mental traits in man. Strictly speaking, "mental" traits are also physical traits, because they are dependent on the structure of the nervous system and the functioning of the ductless glands. For convenience, however, it is customary to separate the two. Intelligence, personality traits, and behavior in general may be called mental.

It is difficult to define the term *intelligence;* one useful definition states that intelligence is the ability to obtain knowledge and to apply it in solving problems. It is thus quite different from knowledge. As you know, it is common practice nowadays to give intelligence tests to school children so the school may know what to expect of them. These tests contain questions that require certain kinds of knowledge that children are expected to have obtained by the time they reach a certain age and other questions that test the ability of the child to apply this knowledge to problems of many kinds.

The score that is made on the test, when compared with the age of the child taking the test, enables the examiner to state the Intelligence Quotient of the child. This is called the I.Q. The figure shows the graph or curve obtained when the I.Q.'s of many children are tabulated.

The use of the intelligence test involves many difficulties. It takes so long to give an individual test that there are not enough experts to do the work nor enough money to pay them. It is customary, therefore, to give group tests. These are helpful because



Adapted from L. M. Terman

FIG. 497. A graph showing the Intelligence Quotient of 905 children. What I.Q. is characteristic of the greater number of children?

they show how the individual probably compares with other members of the group but they are not as accurate as the tests given by experts. Also, since the intelligence test is written in English any child who is not familiar enough with the language will receive a lower score than he should have. There are other factors that tend to make intelligence tests inaccurate.

However, although Intelligence Quotients are often inaccurate, testing shows up clearly the two extremes — the highly intelligent and those of very low intelligence, known as feeble-minded. Feeble-mindedness is vaguely defined as intelligence so low that the person is unable to meet the conditions of life satisfactorily. But of course there are all degrees of feeble-mindedness. The scores of the lower grades of feeble-minded are not shown in the graph. Such people need supervision and care throughout their lives for the same reason that a child needs care. There are many institutions for the feeble-minded. Here the children are helped by specially trained teachers so that in their own little community they may be useful citizens.

Insanity must not be confused with feeble-mindedness. It is not a lack of intelligence. There is still much to be learned about insanity although it is known to be a disease of the nervous system. It takes different forms, many of which are curable. As in the case of other diseases a tendency toward it may well be inherited.

What records seem to show about the inheritance of mental traits. It would seem reasonable to believe that mental traits are inherited. But it has not been easy to find out exactly how such traits are inherited. The simplest cases to study are those of feeble-mindedness, since this is a trait which can be measured with a fair degree of accuracy. An institution for the feeble-minded at Vineland, New Jersey, has made interesting studies of the families of the inmates. One of them deals with the ancestry of the so-called Deborah Kallikak, whose real name is withheld. Deborah was born in an almshouse and brought to the institution at an early age. Her ancestry was traced back to Revolutionary times when Martin Kallikak, a soldier, had a son by a feeble-minded girl. From this union came a large number of descendants who have been traced for five generations down to the present time.

Four hundred and eighty descendants of this feeble-minded girl have been traced. About many of these nothing definite could be learned but 143 are said to have been feeble-minded and 46 normal. After the war Martin Kallikak married a normal woman and thus started a second line of descendants. Four hundred and ninety-six of these have been reported on; as far as the records show all were normal and good citizens.

There are interesting pedigrees of the opposite kind. Jonathan Edwards, a brilliant New England clergyman of colonial times, married a woman of very superior intelligence. Almost 1400 descendants have been traced. Sixty were physicians, one hundred were lawyers, more than a hundred were clergymen or missionaries, thirty were judges, sixty were authors, many held high public office, thirteen were college presidents, and others were prominent in one way or another.

Studies have been made of many other families in which in each generation there appear outstanding citizens. Pedigrees often show the reappearance in each generation of special abilities or skills. Boat designing and musical ability are often found in many members of a family and may go back for generations. These pedigrees are often cited as evidence that mental traits are inherited.

Criticism of the evidence presented. In all these cases we are unable to make the careful observations which a scientist needs for drawing reliable conclusions. We must depend on records written many years ago. These cannot be verified. They were written by people who, in general, were not trained to be accurate. Frequently they were written by people who were prejudiced and who allowed their prejudices to color their reports. It is only recently that men have attempted to keep scientific records for future studies.

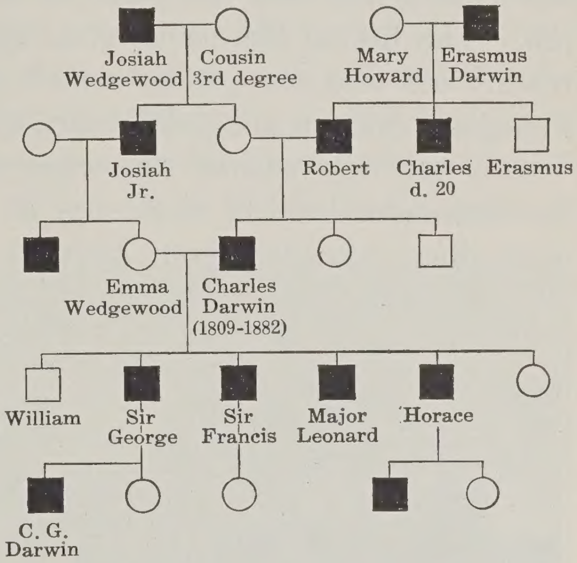
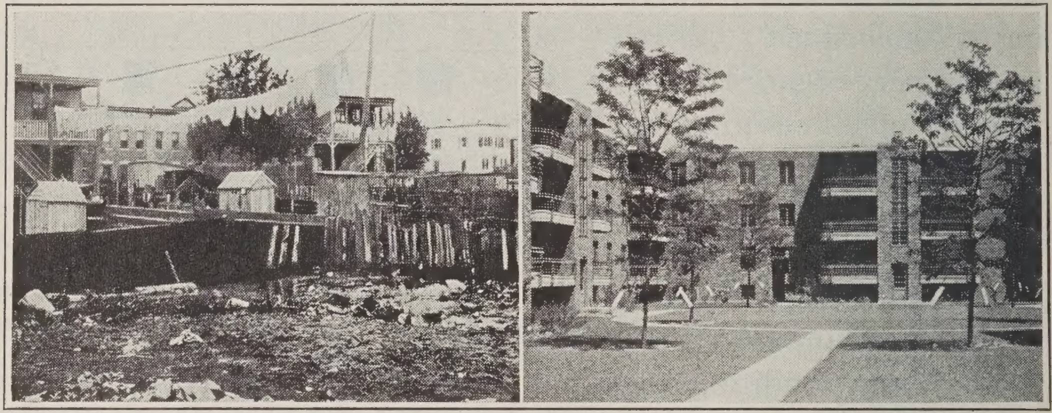


FIG. 498. A part of the pedigree of five generations of an illustrious family. Note the cousin marriages.

But a far more important criticism of all these studies is that the effect of the environment has not been taken into account in arriving at conclusions. As you know, every organism is the product of its environment and heredity combined; the two cannot be separated. The fruit fly with a definite gene for vestigial (short) wings may under certain temperature conditions develop wings that look almost normal. What is true of plants and other animals is just as true of human beings. Until one knows to what extent the extremely undesirable environment of one branch of the Kallikaks and the far better environment of the Edwards affected each individual of these families one cannot be sure to what extent their traits were due to inheritance. There is no way of determining this at the present time. The most reasonable conclusion seems to be that heredity plays an important part in determining ability because it sets limits which even the best environment cannot change. In general, however, it would seem that most persons do not fully develop the powers that their heredity supplies.

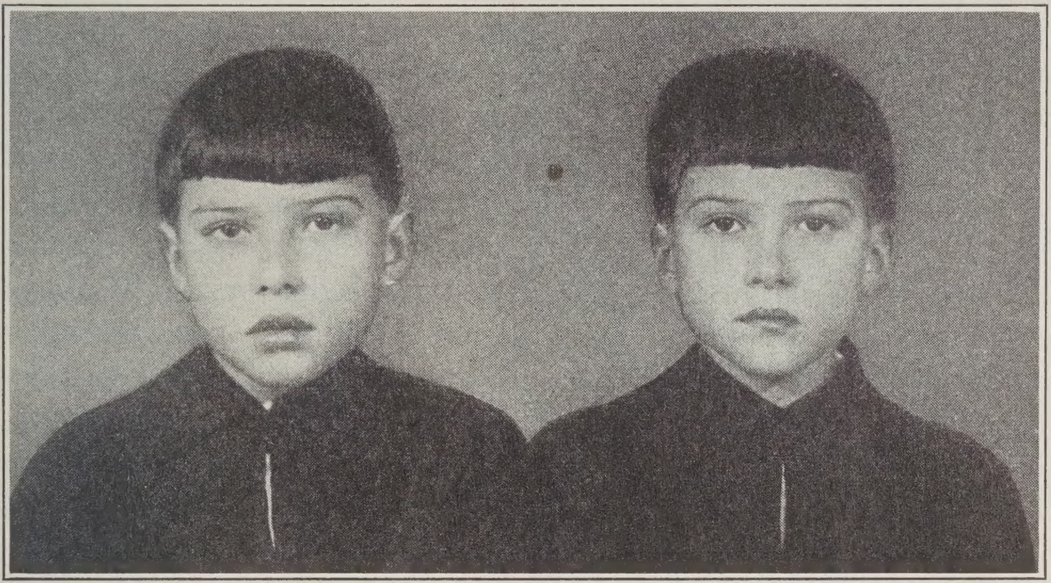
What is known about the effect of the environment on physical and mental traits? The environment of a human being is, of course, far wider than that of a less complex animal or of a plant. It includes the usual factors such as climate, food, air, light, and other living things. But in the case of a human being the other living things play a very important part. They touch his life directly or indirectly each moment from the time he is born until he dies. Your environment includes not only your family but your teachers, your classmates, and your other friends. It includes churches, places of amusement, books, newspapers, magazines, advertisements, and the place in which you work if you have a job. The list of factors of your environment is long. You can readily see that the job by which you will eventually earn your living will make a great difference in the kind of life you will lead. This is not only because the wages you will receive will vary with the particular kind of work you do but also because the kind of work done influences your opinions. The housewife usually has a point of view different from that of the office worker, who in turn has a point of view different from that of the factory hand. *Exercise 5.*



Am. Mus. Nat. Hist. *Courtesy P.W.A.*

FIG. 499. Different environments. List all the ways in which a child brought up in the model home has a better environment.

In an attempt to find out the importance of the environment in determining mental traits biologists have recently turned to a new type of investigation. They have been making observations on identical twins. In this way they come as close as they ever can come to a controlled experiment on human beings. Identical twins have the same genetic make-up. They are formed from a single fertilized egg when, in the early stages of cleavage, two equal masses of cells separate. Each gives rise to a child. There are other twins which develop from two separate egg cells fertilized by two separate sperm; these are no more alike than any two brothers and sisters. But identical twins, as you can see, must have the same gene make-up and can well be used for making scientific observations. All the measurements that have been made show that identical twins, even when brought up together, tend to show differences. But they vary more in certain traits than in others. For example, they are more nearly of the same height than they are of the same weight. They vary in general intelligence about as much as they do in weight. Evidently, the environment plays a more important part in the determination of weight and intelligence than it does in the determination of height. And, evidently, an environment which would seem at first glance to be the same is not the same. Even twins that are brought up together do not have exactly the same environment. *Exercise 6.*



Courtesy Journal of Heredity

FIG. 500. Identical twins have the same gene make-up.

But these studies still do not show the extent to which the environment affects a character. To test this in a general way two identical twins might be placed in very different environments. But parents do not wish to perform such an experiment. Instead, biologists have succeeded in locating identical twins who, for one reason or another, had been separated shortly after birth. Since identical twins start with the same gene make-up, any differences found between two twins brought up in different environments must be caused by the environment. If the differences are slight they show that the environment has had only a small effect; if large, that the environment has had a great effect. Nineteen cases have been very carefully studied and measured by one group of scientists. In physical traits the twins brought up in different environments showed comparatively slight differences. In several cases in which the environments were most unlike the differences in Intelligence Quotient were astonishingly large. In one pair the I.Q. difference was 17 points, in another 19, and in a third as much as 24 points. The conclusion is drawn that the environment has a great effect on "intelligence" and the ability to succeed in school. The investigators went further and studied the personalities of these identical twins that had been separated in early childhood. They found great differences in personality and in character as well. *Exercises 7, 8.*

What conclusions may be safely drawn about the inheritance of mental traits? Scientists have shown that certain types of feeble-mindedness are defects that are passed on by heredity. Recent studies seem to show that one of these types is determined by one or more recessive genes. And there is good reason to believe that other mental traits can be inherited. But since "intelligence," personality, and character are influenced by the environment it is impossible to state how great a part is played by each factor — heredity and environment. Among animals there are breeds or strains that show certain physical and even mental traits whatever the environment may be. The same must be true of human beings, for their germplasm is also continuous. But as you learned from your study of genetics, in each mating there is a chance combination of genes. You cannot predict what combination will occur; but it is probable that a genius will not be born in a family that lacks genes for high intelligence; he might appear in a family whose genetic make-up is good.

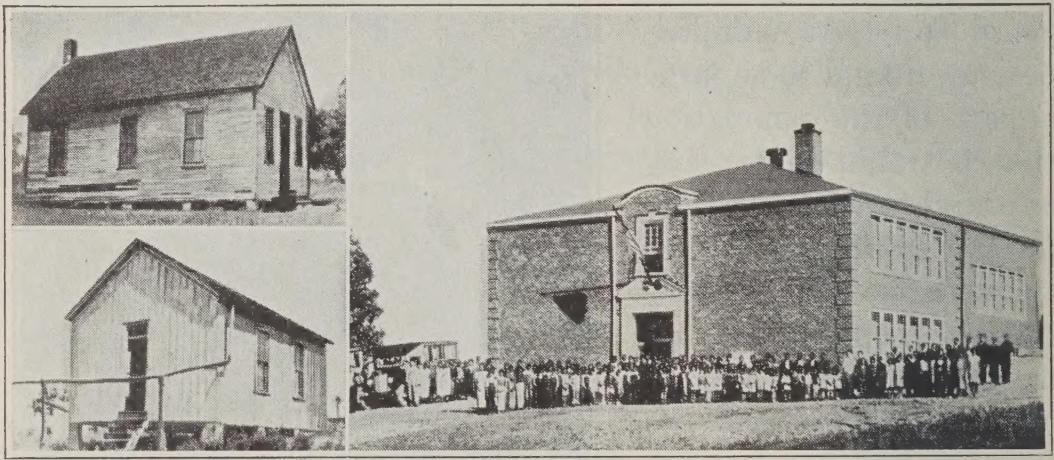
Improving the human race through applying the laws of genetics. In the years between 1906 and 1927 in Great Britain the recorded number of feeble-minded increased 100% while the population as a whole increased only 14%. This may have been the result of more careful investigation of children's intelligence or it may have been the result of an actual increase in feeble-mindedness. To prevent such increase several steps are being taken in this country and elsewhere. Wherever possible the feeble-minded are segregated in institutions where they will be unable to pass on their defective germplasm. Some states in this country have followed the example set by Wisconsin of passing a law which requires a medical certificate of all applying for marriage licenses. It has been suggested that this might be made to include a mental as well as a physical examination. Other states by enforcing sterilization keep feeble-minded men and women from having children. This is accomplished by an operation which affects the person in no other way. It is difficult to decide how helpful such measures can be. Some scientists believe that the recessive genes for feeble-mindedness are found in so large a part of the population that it would take many centuries to wipe out feeble-mindedness. Others think that occasional mutations keep adding undesirable genes to human germplasm, so that we must make provision for the feeble-minded in institutions but not expect to get rid of them.

Courtesy Nat. Child Labor Committee

FIG. 501. This boy spends many days in the open mine. How might this affect his rating on an intelligence test?

There is a different way of attacking the problem of eugenics. It has been suggested that desirable parents should have larger families, the undesirable parents smaller ones. This might be achieved by giving a cash bonus to those desirable parents who raised families of three or four children. But this suggestion has many dangers. The question at once arises: which are the desirable and which the undesirable. Those who have money and power tend to consider their own group desirable; often it is said that the poor are poor, by and large, because they lack ability and ambition. But consider for a moment the qualities which often help to make a man successful: a desire to accumulate wealth and to have power, a willingness to crowd other men to the wall. Which group has the "desirable," which the "undesirable" traits? It would be difficult to know which qualities should be bred for, even if it were possible to suggest practical measures. *Exercise 9.*

Improving the human race by improving the environment. You have seen that improving the human race through breeding (eugenics) is a difficult task. Improving the environment and thus enabling the human race to improve is far easier. This is known as *euthenics* in contrast to eugenics. Many communities guard the health of their citizens by careful disposal of sewage, control of water supply, inspection of foods, and prevention of epidemics. Hospitals and clinics are made available. Even in crowded cities, some space is set aside for playgrounds, parks are laid out, slums are torn down, and better houses built. Schools are provided, education made compulsory, child labor laws are passed, and vocational guidance bureaus established to help young people find suitable jobs. There are libraries, theaters, and other places of recreation and amusement. More recently there have been attempts to reduce worry and strain in adults by regulating seasonal industries, by passing workmen's compensation laws, and by planning for old age security. Much has been done in the United States and in many other countries to improve man physically and mentally. But much remains to be done. Many scientists are convinced that improvement of the race may be gained most quickly by such euthenic measures as the elimination

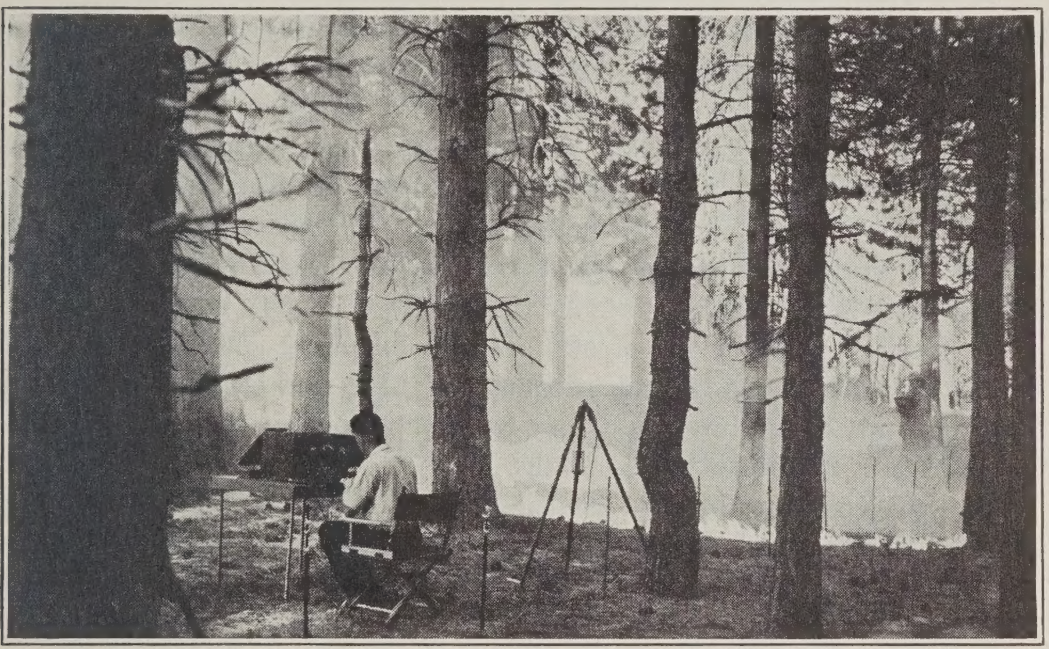


Courtesy P.W.A.

FIG. 502. The little old wooden buildings at the left were two of ten schools to which Negro children in Kentucky used to go. The modern brick school has replaced them. How does this aid the welfare of our country?

of slums and the general improvement of standards of living for all. *Exercises 10, 11, 12.*

What makes improvement possible? Many of the improvements made by man in his environment have come about within recent years. It was when man began to apply the scientific method more generally that rapid progress came. He learned to understand something of his environment and of himself. He made discoveries and inventions that gave him more leisure and more comfort and security in life.



Courtesy U. S. Forest Service

FIG. 503. This fire was deliberately started by scientists so that they might study it. Such experiments may save lives as well as dollars in the future. Wisely used, science can make for greater human happiness.

Science has given man much more than comfort and leisure. It has taught him to banish fear and conquer superstition to a great extent. But man knows that until he has learned to employ methods of science at all times throughout his life there can be little real improvement in the race. He must train himself to observe closely, to suspend judgment, to weigh facts carefully, to reason accurately, and to report truthfully. He must use the methods of science not only in the laboratory but on all occasions. It is in this way that progress can be made. Science points the way toward human improvement. *Exercises 13, 14, 15.*

Exercises

1. Study the pedigree illustrating shortsightedness. Using the letters *n* (normal) and *S* (shortsighted) illustrate this pedigree by using letters instead of squares and circles.

2. The class secretary might write to the Eugenics Record Office, Cold Spring Harbor, N. Y., for a sample of the type of blank used.

3. Careful study of the pedigree illustrating the inheritance of an abnormal skin condition will show whether the character is caused by a recessive or dominant gene. Explain the genetic make-up of each individual that shows the defect.

4. Can you find out about any unusual character (no matter how small) in your family, or in that of some friend's family? Obtain all the information you can and construct a chart. Be sure to state fully the sources of your information; your classmates will want to know how reliable your facts are.

5. Prepare a short list of occupations, including such work as coal mining, nursing, teaching, and waiting on table. For each type of work name the part of the body that may be affected or injured. Discuss this with adults and with your classmates.

6. Can you explain why identical twins are likely to vary less in height than in weight? Explain in what respects the environment of twins brought up in the same family and going to the same school might be different.

7. From your own experience and by reading reliable articles on identical twins (such as in the *Journal of Heredity*) prepare a report to the class. There are books on the subject that you can consult.

8. Look through the files of newspapers carefully for news items on heredity in twins or related topics. Bring information to class and discuss. How much of what you read can you believe? Which tend to be more reliable, these news items on twins or those on such a subject as "changes in the earth"? Explain.

9. Discuss with your family the possibility of arriving at a decision as to which genes are desirable and which undesirable. In general, do the most intelligent people earn most? Write down your thoughts in an orderly way and discuss them with your classmates.

10. Find out what stand your state has taken on the subject of child labor. Find out which states have failed to ratify the amendment.

11. Add to the list of ways in which man has improved his environment within the last century. How did Peking man improve his environment? How did Cro-Magnon man? What is meant by "civilization"?

12. A person who raises his I.Q. 24 points by having a better environment is not changing his germplasm. Explain fully how he can improve the race in spite of this.

13. Make as long a list of superstitions as you can. Discuss these with the class. Try to determine how each arose. Show how science has freed man from unnecessary fears.

14. *Summary.* In this section you learned something about the history of eugenics, the methods of study used, what the records seem to show about the inheritance of physical and mental traits, the effect of the environment, what suggestions have been made for the improvement of the race. Can you discuss these topics? If you have read carefully you have learned the danger of drawing conclusions without evidence. Where was this shown?

15. *Unit Summary.* To summarize this unit you will have to travel far into the past and into the future. Combine your summaries of sections 1 and 2 and try to imagine on a basis of what happened in the past what may happen in the future. In which directions do the possibilities of betterment lie?

Activities for the Junior Biologist

1. Read up on the cost of feeble-mindedness to the United States. See M. F. Guyer's *Being Well Born.*

2. You may be interested in reading about the Kallikaks in more detail (Goddard's *Kallikak Family*). You will also read how the feeble-minded are trained.

3. If you are interested in reading about the Edwards in more detail, read John Langdon Davies's *New Age of Faith.*

4. If you have never taken an "intelligence test" ask your teacher to show you one. Look up a Binet-Simon individual test.

5. At the time of the World War intelligence tests were given to the soldiers. Look up the results and if possible show your figures in a graph.

6. A. E. Winship has written a little book on the Edwards family. Read this and make a list of all the questions suggested by the book that you would like answered before you arrive at any conclusions.

7. If some of your classmates are interested, organize a committee to study the ways in which the environment provided by your community might be improved. This activity will undoubtedly extend over a long period of time. You might provide for a series of committees for several terms.

8. Some euthenic measures, such as the Child Labor Amendment, are in dispute. Organize a discussion (*not* a debate) in which the facts may be presented and considered.

Good Books to Read

Bean, R. B., *The Races of Man.* Univ. Society.

Boas, F., *Anthropology and Modern life.* Norton. *The Mind of Primitive Man* (Rev. ed., 1938). Macmillan.

Boyle, M. E., *Man before History.* Little, Brown.

Clodd, E., *The Childhood of the World.* Macmillan.

Cowdry, E. V., *Human Biology and Racial Welfare.* Hoeber.

Downing, E. R., *Elementary Eugenics.* Univ. of Chicago. *Science in the Service of Health.* Longmans, Green.

Fasten, N., *Principles of Genetics and Eugenics.* Ginn.

Graves, F., *Man in the Making.* Putnam.

Haggard, H. W., *Devils, Drugs and Doctors.* Harpers.

Holmes, S. J., *Human Genetics and Its Social Import.* McGraw-Hill.

Huxley and Haddon, *We Europeans.* Harpers.

Kroeber, A. L., *Anthropology.* Harcourt, Brace.

Linton, R., *The Study of Man.* Appleton-Century.

Peak, H. T., *Early Steps in Human Progress.* Sampson Low, Marston and Co.

Quennell, M. and C. H. B., *Everyday Life in the New Stone, Bronze and Early Iron Ages.* Putnam. *Everyday Life in the Old Stone Age.* Putnam.

Shapiro, H. L., *The Heritage of the Bounty.* Simon and Schuster.

Shetrone, H. C., *The Mound Builders.* Appleton-Century.

Verrill, A. H., *Before the Conquerors.* Dodd.

Wells, H. G., Huxley, J. S., and Wells, G. P., *The Science of Life.* Doubleday.

INDEX

Figures in boldface indicate pages where definitions and pronunciations occur. * indicates pages where illustrations occur.

Abdomen, **74**
Abnormalities, 336*, 341
Absorption, 274, 275, 280
Accessory food substances, **214**
Acid, 275; amino, 264, 272
Acquired characteristics, **691**, **692**, 694, 695; immunity, 495, 496
Active gamete, **419**; immunity, **515**, 517; immunization, 520, 521
Adaptations to environment, 461, 464–474, 598, 730, 740, 742
Adrenal glands, **338**
Adrenalin, **339**
Adrenin, **337**, 338, 339
Aerated blood, 306; water, **462**, 465, 466
Aerial roots, 202
Aerobic bacteria, **525**
Afferent neurons, **373**, 379
African sleeping sickness, 479, 535
Agar, 132, 502*, 503, 505, 506, 532
Agaricus, **137**
Ages, prehistoric, 638–645, 720, 721*, 722*, **744**, 745*, 753–755; reading on, 772; rocks, 627, 628
Agglutinins, **494**
Agriculture, 577, 593, 601; Yearbook of, 688, 706, 707, 714
Air, 125, 205, 206, 209*, 317, 328, 353, 461, 462; bladders, **464***; bubbles, 175; composition, 187, 188, 191; polluted, 589; sacs, 308, **309***, 310–313, 316
Albinos, **759***
Albumen, **432**, 433
Alcohol, 257, 283, 292, 307
Alfalfa, **148**
Algae, 130–**132**, 584
Alimentary canal, **269**–271, 273, 274, 276, 277, 283–285, 287–289
Allen, A. A., 8*
Alligators, **57**, 58, 564
Alternate domination, 599
Alternation of generations, **445**, 446
Amanita, 132*, **133**
Amber beds, fossils, 622
Ameba, **122***, 123, 127, 175; behavior, 189, 358, 359*; digestion, 283; elimination, 325; food, 288, 294; reproduction, 410, 411, 416; response, 362, 550; structure, 550; *see also* Microorganisms
Amino acids, **264**, 272
Ammonium compounds, 575; hydroxide, 187
Amphibians, **59**–64, 153, 315, 463, 469, 471, 564*, 721*; reading on, 64, 71; reproduction, 455
Amylase, **272**
Anabolism, **329**, 340
Anaconda, **56**
Anaerobic bacteria, **525**, 534
Ancient Life, and Modern Man, frontis.
Ancon sheep, **704***
Andalusian fowl, 679
Andrews, Roy Chapman, 11, 625, 632
Anemia, **293**, 306
Anemic, **479**
Anemones, **112**
Animal breeding, 702–704, 709, 710, 714; cells, 171–177, 226, 290, 329; ingenuity, 35, 407
Animals, 13, 115, 121, 153, 167–178, 548, 549, 571, 580, 646; behavior, 380–399; carnivorous, 27, 28, 471, **486**; classification, 18–22, 566, 568; digestion, 283–286, 288; domesticated, 26, 61, 62, 88, 698; environment, 461–474; evolution, 717–720; geographic distribution, 738–740, 742, 743; herbivorous, 25–27, **285**, 288, 592; higher, 329–342, 399–407, 423, 455, 656, 657; invertebrate, 73–119, 415, 423, 435, 455, 467; learning, 388; many-celled,

117, 283, 284, 368–399, 422, 431, 558; microscopic, 117, 120; nutrition, 213–220, 232–242; offspring, 450–456; omnivorous, **288**; phyla, 20–127, 307, **582**; protections, 486–493; reading on, 24, 35, 119, 460, 499, 608, 609, 647; reconstruction, 623, 626, 719*; reproduction, 408–437; single-celled, 325, 410–412; structures, 368, 549–568, 736, 737; tissues, 174; vertebrate, 20–72, 288, 303, 399, 415, 563, 718, 733
Annelida, **109**
Annuals, **228**
Anopheles mosquito, **479**, 480*–484, 528, 541*
Antarctic zone, life, 470*
Anteaters, **30**
Antennae, **74**, 75, 102
Anthers, **439**, 446, 658
Anthrax, **507**, 511, 521; bacillus, 494*
Anthropology, 752, 772
Antibodies, **494**–498, 512, 517, 520, 525, **567**, 569
Antiseptic surgery, **514**, 521
Antiseptics, **504**, 506, 524
Antitoxins, **493**, 494, **516**, 517, 519, 522
Antivaccination movement, 523
Antlers, elk, 26*, 487
Ants, 85, **86***, **87***, 88*, 455, 460; reading on, 93, 407
Aorta, 299, **300***
Apes, 25, 34, 455
Aphids, **82***, **87**, **430**, 540*
Apparatus, electrolysis, 186; for measuring energy, 246*
Appendages, 74*, 91, 102, 734*
Apples, 538, 539*; core, 444*
Appleseed, Johnny, 608
Aquarium, 22, 71, 115, 118, 231, 574*, 580, 587
Aquatic Microscopy, 128, 570
Arachnids, **94**–97
Arcella, **123***
Archaeornis, imprint, **640***
Archeozoic era, **628**, 635
Arches, gill, **314***
Arctic, The Friendly, 12
Arctic zone, 470, 471, 473, 474, 546
Arcturus Adventure, 12
Aristotle, 15
Arm, 303*, 563*
Armadillos, **30***
Armored Animals of the Seashore, 102
Arteries, **295***, 296*, 297, 307
Arthropods, **73**, **74**, 102, 153; reading on, 102
Artifacts, **744**, 745*, 756
Artificial mutations, 683, 684; parthogenesis, **431**, 437; pollination, 681, 714
Aseptic surgery, **514**, 521
Asexual reproduction, 408–417, **418**, 444–446, 449
Assimilation, **225**, 227, **242**, 246, 247, 261, 262, 287, **548**, 550
Athlete's foot, 478, 484
Audubon, 604, 607, 608
Auk, 603
Auricles, **295**, 298*, 299, 300*, 301*, 305, 306, 735*
Australian fauna, 738, 739; ladybird beetle, **600**; mammals, 34, 594, 596, 598
Autonomic nervous system **405***, 406
Autumn foliage, 207; shrubs, 157
Aves, *see* Birds
Axons, **369***, 371–373, 377, 380
Azoic era, **628**

Baby-clinic, 525*
Bacilli, 494*, 504, 507, 508, 519*, 530
Backbone, animals with, 20–72, 325; fish, 65; snakes, 52*, 53
Backcross, **679**
Backswimmer, 83*
Bacon, Francis, 524
Bacterial parasites, 544
Bacteriology, 499, **500**, 501, 521, 526, 609
Bacterium, 125, **126***, 127, 132, 154, 267, 478, 493*, 494, 497, 500–525, 532, 533, 579; aerobic, 525; anaerobic, 525; denitrifying, 575; experiments, 409; invisible, 491; nitrifying, 575; nitrogen-fixing, **576**, 584; pathogenic, **492**; reading in, 128, 138, 547; *see also* Germs
Bactrian camel, 27*
Balance, in relationships, 588; of life, 580–599; sense of, 370
Ball, 427, 442, 650*; *see also* Blastula

Banded tree, 541*
Bark, 348, 350*, 351*, 353, 355, 537*
Barley, 684*
Barnacles, 98, **99**, 100*
Barriers, **738**, 739, 743
Basic, 281; activities, 548; similarities, 561, 562, 568
Bates, Henry Walter, 3
Bathysphere, **6***, 474
Bats, **33***, 34
Baxter, L. H., 49
Bayliss, Physiology, 560
Bean seeds, 443*
Bears, 19*, 35, 623*
Beasts, Life Story of, 35
Beavers, **29***, 34, 35, **383**
Beebe, William, **6***, 474
Beef, 176, 315, 326; cattle, 709, 710
Bees, **87**–89*, 92, 370*, **430**, 497; reading on, 93, 460
Beetles, **83**, 84*, 85, 537*, 545, **597**, **598**; ladybird, **600**
Beets, 194
Behavior, 358–407; chromatin, 651, 652; complex, 399–407; experiments, 383–388; inborn, **404**; instinctive, **382**–384; intelligent, 360; learned, **386**; man, 391; plants, 362–368; protoplasm, 186; protozoa, 358–362
Benedict's solution, 187
Beriberi, **250**, 251, 258*
Bermuda Islands, 615
Bernard, Claude, 334
Biennials, **228**
Bile, 270, 275
Bill, bird, **217***, 433
Binary fission, **410**
Binet-Simon test, 771
Biological Survey, Bureau of, 604, 607; Supply Co., 49, 189
Biologists, 1–12, 159–163, 507, 526, 534, 549–554; experiments, 163–166, 661–663
Biology, reading on, 24, 189, 190, 223, 289, 357, 460, 499, 560, 570, 743, 772
Birds, **36***–50, 153, 217*, 325, 471, 562*; banding, 48; brain, 564*; cenozoic era, 643; feathers, 36, 424; feeding stations, 49; flight, 47; food, 41, 216, 217, 222, 223; heart, 735*; laws, 605; migration, 44–46; nests, 43; parental care, 452, 453, 459; plumage, 41; protection, 543, 544; reading on, 49, 50; reproduction, 432–436; teeth, 36
Bird's foot violet, 605*
Bison, 19*, 23, **26**, 603
Bivalves, **103**, 105, 119
Black ants, 86*; widow spider, **95**, 101
Black Death, 528
Black Hole of Calcutta, 328
Bladder, 321; air, **464***; swim, **473**, 474
Blastula, **427**, 437, **564**, **648**
Bleeding (a horse), 516*, 517
Blending inheritance, 667
Blepharisma, 416, 561
Blind, **9**
Blister rust, white pine, **597**, 598*
Blob, **635**
Blood, 274, 290–319; aerated, 306; cells, 293*; circulation, 295–304, 306, 307; clotting, 294; composition, 293, 304; deoxygenated, **300**; earthworms, 303, 315; man, 306; oxygenated, **300**; plasma in, **292**, 293; poisoning, 513–514; pressure, 307; reading on, 357; stream, 294, 295, 308, 320, 321; sugar in, 334; thyroxin in, 331; transfusion, 307; vessels, 176, 276, **290**–292*, 304, 307
Bloodhound, 338*
Blossoms, 144, 145, **438**, 446, 447, 661*–663; *see also* Flowers
Blue Andalusian Fowl, 666*
Blueberries, 708*
Boa constrictor, **56**
Board of Health inspector, 530*; protection by, 527, 528; worker, 510*
Bobcat, *see* Canada Lynx
Body cavity, **169***, 173*; cells, 268–283, 302*, **329**, 422, 584–599; reading on, 189, 260, 283, 357; temperature, 324, 325
Boll, 593*; weevil, **593***, 599, 600
Bones, **174***, 176, 229, 463, 563; fossil, 625*; leg, 716*, 717
Boston ivy, 202
Botanic Gardens, Brooklyn, N.Y., 681

Botanist, **129**
Botany, **1**; reading on, 24, 190, 223, 357, 460, 570
Boy in mine, 767*
Boy Scout, Handbook, 319; Merit Badge, 48; Museum, 9*
Boyle, Robert, 522
Brachydactyly, **759**
Bracket fungus, 133*
Brahman bull, 710*; Brahman Shorthorn cattle, 710
Brain, 276, 277, 370*, 399, 400*, 406, 407, 536, 564*, 566, 567, 569, 572, 734
Brand, A. R., 49
Bread mold, **133**, 412, 416, 477
Breathing, 310, 311, 317–319, 434, 464, 466, 542
Breed, true, **667**, 677, 681, **686**, 700, 702–704, 707
Breeders, animal, 671, 714; plant, 671, 710, 714
Breeding, 661–675, 680, 681*; close, **700***; experiments, 661–675; 704–706; habits, 541, 554; reading on, 696, 756, 757
Bronchial tubes, 308*, **309**
Brontosaurus, **641**
Bronze Age, **754**, 755, 772
Brooks, 102, 119
Brown algae, **131**, **464**, 465
Bryophyllum leaf, 415*
Bryophyta, **135**, 136
Bubonic plague, 528, 529, 535
Budding, 411, 417
Buds, **229**, 230, **411***, 414; mutation, 712; variation, **705**
Buffalo tree hopper, 83*
Bulb, **414**, 415*, 416
Bull, 703*, 710*
Bulldog, 338*
Bullfrogs, **61**; *see also* Frogs
Bugs, **82**, 83
Bumblebee, **87**, 449
Bundles, 349, 350, 353
Burbank, Luther, 708
Burdock, 457*, 459
Burning, 186, 188, **235**, 239, 241
Butter, 187
Buttercups, 733
Butterflies, **76***, **78**–80, 91, 92, 93, 221, 490, 537, 538
Cabbage, butterfly, **76**, **537**, 538; family, 733
Cactus, fish-hook, 470*
Calcium, 182, 340
California desert, 469*
Calories, **237**, 241, 246, 256
Calorimeter, **238***, 243
Calyx, **438**
Cambium, 350*, **351***, 352*, 357, **711**
Cambrian period, **629**, 636*, 637, 646
Camels, 7*, **26**
Camera, 10*, 12, 178
Canada lynx, **28**
Canadian Rockies, 12
Canal Zone, 542
Canary birds, 598
Canine tooth, **278**
Canis, **17***, 18*, 23, **736**
Cannon, Walter B., 276
Capillaries, **291**, 292*, 297*, 301, 306, 308, 309*, 323
Capsule, moss plant, 135*
Carbohydrates, **183**, 184, 188, 206–208, 210, 248, 264, 275, 334
Carbolic acid, 514
Carbon, 178*, 313, 317, 328, 572; compounds, 573; cycle, **579**, 580, 586
Carbon dioxide, 186, 187, 306, 466, 573
Carboniferous period, 638, **639***
Carleton, M. A., 707
Carnivores, 19*, **21**, **27**, 28, 285, 288, 471, **486**
Carrel, Alexis, 165
Carriers, **527**–529, 532, 536
Carrots, **227***, 354
Cartilage, 66, **174***, 176, 315
Castings, **110**
Catabolism, **329**, 340
Catalysts, **264**, 266, 267, 281, 282
Catamount, *see* Wildcat
Caterpillars, **79**, 456*, 489*, 541*
Cats, 11, 23, 27, 28, 296, 674*, 682, 736
Cattalo, **710**
Cattle, 687, 702–704, 709, 710*
Caucasian, **751***
Cecropia moth, **79**, 92, 231
Cedar, 141*
Cell division, 229, 410–412, 556, 651–653, 659; doctrine, 554, 560; theory, 553, 554; vacuole, **555***, 556; walls, 177, 555*

Cells, **169**, 170*, 175, 184, **261**, **262–267**, 269, 270, 276, 301, **553**–555*, 556*, 557; animal, **171***, 172*, 173*; blood, 290–292, 293*, 294; body, **171**, 173*, 302*, **329**, 418–423, **555***; cambium, **351**; cortex, 403; daughter, 410, 411, 653, 657*; egg, **440**; effectors, **373**; epidermis, 206, 357; food-storing, **442**; fusion, 418–421, 423; guard, **194**; higher animals, 329–342, 403; membrane, **555***, 557*; nerve, 557; neuron, 369, 370, 373; palisade, **211**; plant, 171, 172*, 209, 210, 228, 229, 267, 349, 555; pyramidal, **401***; reproduction, 418–422, 440, 442, **649**; resting, **430**; root, 555*, 556; secreting, 265, 323; stained, 653, 654*, 655; structure, 170–174; tetanus, 519; tissue, 174, 557, 558, 568, 648, 649
Cellulose, **171**, 226, 285; walls, 349, **555**
Cenozoic era, **629**, 642–644
Centipedes, **97**
Central Asiatic Expedition, 3*
Central cylinder, **349***
Centrosome, **556**, **654**
Cerebellum, 371*, **399**, 400*, 404
Cerebrum, 371*, **399**, 400*, 404
Chambers, heart, 434
Chameleon, **57**; habits, 63
Changes, balance, 584–586, 588–598; chemical, 279; chromosomes, 681–688; earth and inhabitants, 610–617, 633–645, 647; embryo, 443, 444; environment, 359, 360; in types, 697–743; physical, 267; plant substances, 201, 205; relationships, 580–584
Channels, 623*, 624
Chaos chaos, **558**
Character, *see* Characteristics
Characteristic number, 655
Characteristics, **14**, 15, 566, 610–647, **661**, 682–687, 693; acquired, **691**, **692**; animals, 34, 36, 51, 59, 65, 74, 94, 98, 103, 116; contrasting, **661**, 666–668; dominant, **666**; four o'clock, 661; genera, 23; horse, **717**; inherited, 666, 667, 671, 672, 758–763; mammals, 20, 31, 32, 34; orders, 21; plants, 129, 130, 562; primates, 21; protoplasm, 550; races, 752; recessive, **666**; secondary sexual, 423, **424**, 425*; sex-linked, **677**; unit, **674**, 675; vertebrates, 20
Cheek, **176**, 270
Chemical changes, 267, 279, 575, 633; energy, 236; resemblances, 567, 568
Chemicals, 361, 364, 450, 493, 494, 497, 503, 504, 524, 532, 539, 540
Chemist, **178**, **180**
Chemotropism, **364**
Chest cavity, 310, 311*, 315, 316
Chestnut tree, leaves, 143*
Chewing the cud, **285**, 289
Chickadee, 43*
Chicken, 250*, 435–437; cholera, 511
Children, 459, 518, 522, 761, 770
Chimpanzee, 25, 403*
Chinch bug, **540**
Chiroptera, **33**, 34
Chitin, **73**, **555**
Chlorine, 182
Chlorophyll, **206**–210, 212, 287, 443, 445, 549, **556**, 562
Chloroplasts, **206**, 419, **556**
Cholera, **511**
Chordata, **20**
Chromatin, **556**, 557*
Chromosome changes, **686**, 687, 704–706, 725
Chromosomes, 651, 652*, 654*, 657*, 660, 678; changes in, 681–688; composition, 658, 659; four o'clock cross, 663; giant, 677*; maps, 675; numbers, 653, 655, 684; sex, 676; species number, 655, 656; table of, 655, 659
Chrysalis, **76***
Cicada, **90**, 434*
Cilia, 121, **122**, 123, 317
Circulation, 291, 295, 296, 548; animals, 304; blood, 306, 307; earth materials, 572, 573
Circus freaks, 336, 341
Citron, **708**
City, 157, 588, 589, 598
Civilization, 547, 753–755, 770
Clam, **103**, 117, 119
Class, **18**, 23, **566**, 723, 735; am-

phibia, 59; arachnida, 94; aves, 36; crustacea, 94, 98; insecta, 74; mammalia, 20, 25, 34; myriapoda, 94, 97; pisces, **65**; reptilia, 51
Classification, 13, **14**–23, 566, 568, 742; Haeckel's, 569, 570; Linnaeus scheme, 18, 19, 735; man, 19–22, 752; plants, 129, 130, 137, 140, 141; racial, 752; scheme of, 565, 568; *see also* Phyla
Clay, models, 289
Cleanliness, 527, 533
Cleavage, **427**, 428*, 431, 435–437
Cliff dwellings, 754*
Cliff swallow, nests, 43*
Close breeding, **700**
Clothes moth, **540**, 545
Clotting, blood, 294, 306, 576
Clover, 147, **148**, 449, 576
Coal, 241, 620, 622*, 637–639
Cobra, **56**
Cocci, 494*, 504
Coccyx, **737**
Cochlea, **375**, 376
Cockroaches, 81, 82, 98, 638, 639*
Cocoon, **75**, 79*, 231, 456*, 537, 543
Cod liver oil, 253, 255*
Codling moth, 538*
Coelenterates, **112**–116, 153
Coffee tree, berries, 152*
Colchicine, 685
Cold-blooded animals, **51**, 62, 65, 325
Coleoptera, **83**–85
Coli bacilli, 494
Collie, 18*
Colloidal, mixture, 552; particles, **551**
Colloids, **551**, 552, 553; complex, 556, 571
Colonies, **113**, 502, 505
Color, 67, 416, 443, 661–666; blindness, 380, 676, 677
Colorado potato beetle, **598**
Colorless, blood, 303; plants, 132, 210, 289, 475
Columbus, 149
Combination of elements, 179–181
Comparative anatomy, **564**, 566
Complete, learning, 391–393*, 394; metamorphosis, 434
Complex animals, 380–382, 422–437, 649, 659; behavior, 399–401; hybrids, **708**; plants, 413, 414
Complicated reproduction, 418, 422, 423
Composite family, **152**, 153*
Compound leaf, 146*
Compounds, **180**–182, 185, 186, 188, 189, 191–193, 205, 210; carbon, 573; soil, 573–580
Concentric circles, **176**
Conditioned reflex, 385, 398, 399
Conditioning, **385**, 387, 398
Conduction, **344**, 349
Cone-bearers, **141**, 142, 155, 156
Conjugation, **420***, 422, **648**, **656**
Conquerors, Before the, 772
Conservation, **601**; forest, 601–603; soil, 609; State Department, 607; wild life, 604
Contact poisons, 538, 546
Contractility, **186**, 189, **360***, 373
Contrasting characters, **661**
Convolutions, 400*, **401**
Coordination, **404**
Copepods, **581**
Copperhead snake, 55*
Coral, **112**, 113, 114*, 118, 462*
Cork, 169, **170**, 175, 553
Corn, 193*, 225*, 439*, 443*, 692*, 701*, 713; smut, 477, 478
Cornborer, European, **542**, 598, 599
Cornea, **375**
Corolla, **438**
Corpuscles, **293***, 294, 305, 306, 492
Cortex, **400**, 401*, 406
Cotton, **150**, 151*, **593***
Cotyledons, 212, **447**, 448, 457
Cousin marriages, 763
Cowpox, **515**
Cows, 25, 232*, 285, 289, 515, 699*
Coyote, 17*
Crabs, 94, **98**, 99*, 100, 101*
Crane, sandhill, 39*
Cranium, **20**, 370
Crayfish, **100***, 102, 285, 286*, 289, 303, 304, 326, 327, 455
Creeping molluscs, **104**
Cretinism, **332**
Crocodiles, **57**, 58
Cro-Magnon man, **749***, 750, 770
Crop, **286**, 289
Crops, 205, 535, 536, 577, 579, 593
Crossbill, **41**
Cross-pollination, **441**, 714

Crosses, 661–668, 671*, 672*, 673*, 678, 707–709, 710*; *see also* Breeding and Inheritance
Crossing over, **680**
Crustaceans, **94**, 98–102, 467, **637**
Cuba, 546
Culex, 542*
Cultivated, plants, 688, 698–715; soil, 578*
Cultured bacteria, **500**, 501
Cultures, 175, 189, 288, 416, 417, 504–506, 509, 511, 516; media, **500**–503, 521; of men, **753**–756
Cup, 427, 428, 442, 564, 648; *see also* Gastrula
Curve, *see* Graph
Cushioned feet, animals, **27**, 28
Cuttings, **413**, **711**
Cuvier, 620
Cycles, carbon, **579**, 580, 586; life, 669; nitrogen, 577*; oxygen, 579, 580; water, 599
Cyclops, **100**
Cylinder, **351**, 352; *see also* Rings
Cytology, 570
Cytoplasm, **171**, 177, 348, 374, 410, 412, 426, 439, 440, **555***, 556, 652, 657

Daddy longlegs, **97**, 101
Daisies, **151**, 152, 728*
Dam, beaver, 383*, **703**
Dandelions, 457*, 459
Darning needle, **85***
Darwin, Charles, 110, 725–733, 740, 743
Datura, *see* Jimson weed
Daughter cells, **410**, 411, 416*, 653, 657
Daylight, *see* Light
Death rates, 459, 508*, 516*, 520*
Decay, **523**, 525, 533, **575**, 579
Deciduous trees, **145**
Deep-sea animals, 466–468, 470, 473
Deer, 425*
Defenseless animals, 489–491
Defoe, 534
De Lamarck, 731, 732; *see* Lamarck
Deltas, **613**, 614, 616, 617
Dendrites, 369, 370, 372, 377
Denitrifying, **575**
Dentine, **278**
Deoxygenated blood, **300**
Dermis, **322**
Desert, 35, 468, 469*, 470, 473, 499, 599, 609, 617
Development, 427–429; *see* Evolution
Devilfish, 66
De Vries, Hugo, 685–687, 724, 725, 731–733
Diabetes, **334**, 335
Diaphragm, **310***, 318, 319; microscope, **559**
Diastase, **265**, 266*, 267*
Diatoms, **470**, **581**, 584
Dicot (Dicotyledon), 143*, **145**–152, 155, 156, 350, 351*, **352***, 353
Didinium, **288**
Diet, **215**, 242, 249–251, 253, 256–260, 282
Dietitian, **246**
Differentiation, **423**, 443, 445
Diffusion, **198**, 202, 203, 273, 312, 343, 348
Digestion, 261, 262, **263**–270, 278, 281, 289, **548**; animals, 283, 284, 287; man, 268–283, 287; plants, 286, 287
Digestive, enzymes, 265, 266; glands, 276, 277; juice, 270; system, 266, 268*, 286
Dihybrids, **673**, 679, 681
Dingo, 17*
Dinosaurs, **620**, 627, 641*, 642, 722*
Diphtheria, 493, 515, **516***, 517, 521, 526, 527
Diptera, **77**, 78
Diploid number, **656**, 657, 685
Discs, 61*
Disease, 118, 249, 250, 255, 478–482, 492–498; carriers, 528, 529; causes, 507–511, 523; control, 521; fight against, 507–523; germ basis, 507–511, 521; immunity, 494, 495; infectious, **507**, 526; inheritance of, 759, 760; plant, 496, 499, 536; prevention, 513–523; protection, 491–494; tropical, 528
Disinfectant, **504**, 506, 513
Disinfection, **526**
Dispersal, seed, **457**, 458
Dissection, 117, 118, **167**
Distribution, plants and animals, 738–740, 742, 743; races, 752

Disturbed balance of life, 587–589, 599, 603, 604

Division, 411, 440, 442; ameba, 550; chromosomes, 651–653; cytoplasmic, 657; labor, 423, 436; mitotic, 657; nucleus, 410, 443; paramecium, 410*; zygote, 427, 430, 432, 445

Doctors, 148, 260, 547

Dodder, **485**, 582*

Dogfish, **66**

Dogs, 17, 23, 341, 736; brain, 564*; breeding, 696; experiments, 512

Dominance, **667**, 668

Dominant character, **666**, 672; mutation, **687***, 759

Double fertilization, **447***

Dragonflies, **85***

Drawing, prehistoric, 750*

Drew's Manual, 118

Drinking water, 520, 526, 530–533; polluted, **531**

Drosophila, **670**, 697; *see also* Fruit fly

Drugs, 148, 260, 547

Duckbills, **31**

Ductless glands, **331**, 336, 337, 338, 339, 340

Ducts, **270**, **344***, 349*, 350*

Dujardin, Felix, 549

Dust, 317

Dutch elm, disease, **597**; storms, **590**, 591*

Dutrochet, Henri Joachim, 554

Dwarfism, 337

Eagle, American, 37*

Ear, man, **375**, 376*, 379

Earth, changing, 610–647; history, 618–647; inhabitants, 635–642; materials, **571**–579; origin, 633; reading on, 11, 647, 743; surface, 610–617; theory, 633–635

Earthquakes, 610, **611**, 616*, 617*

Earthworms, **109**, 110*, 118, 119, 284, 288, 303, 315, 326, 327, 370*, 374, 379

Eastman Kodak Co., 178

Eating tube, 112*, 115*

Echinoderms, 107–**109**, 118, 153, 636

Ecologists, 586, 594, 596, 604

Ecology, **580**, 587, 600, 609

Ectoderm, **428**

Edwards family, 762, 771

Eel, **70**

Effectors, **368**, 373, 377, 379, 380*

Efferent neurons, **373**, 379

Egg cells, **424**, 425, **432**, **436**, **440**, 442

Eggs, 424–426*, 437–442, 451, 453, 481, 482, 625*; ants, 455; bees, 88; birds, 459; fertilization of, 430, 434, 649, 650; fish, 70, 426–428*, 430; frog, 426*, 427*; grouse, 432*; haploid, 657; Hydra, 426; maturation, 657; mosquito, 542*; reptiles, 459; slug, 106*; spider, 94*; starfish, 436; turtle, 451*; weevil, 593

Eijkman, **250**, 257, 260

Electrolysis apparatus, 186

Elements, **25**, **179**–182*, 189, 191, **571**

Elephants, **26**, 454, 459, **718**–719*

Elimination, *see* Waste

Elk, American, 26*; wild, 603

Elm, American, 347*; bark beetle, 597; leaf, 146*; trees, 597–599

Elodea, 211, **595**

Embryonic life, **429**, 431, 442, 443

Embryo, **429**, 430, 451, 452, 456, 457; birds, 432; frog, 433; mammals, 431; plants, 442, 443*, 444, 455, 456; sac, **440**, **441**, 442*, 446; structure, 564, 565*; vertebrate, 564, 569

Emerson, A. R., 692

Emulsified, **275**

Emulsion, **275**, 281, 282

Enamel, **278**

End, brush, 372; products, **272**

Endemic, **332**, 340, 341

Endocrine glands, **331**, 337, 340, 341

Endoderm, **428**

Endosperm, **442**, 443, 444, 447, 457

Enemies, *see* Pests

Energy, **233**–237, 239–243, 246, 329

English ivy, 202; sparrow, **595**, 596

Entomology, **9**, 536, **537**, 543

Environment, 607, 688, 692, 763, 764*–766; adaptations to, 464, 473, 729, 740, 741; heredity and, 648–696; improvement in, 698, 699*, 768, 769; physical, 461–474; reading on, 499, 696; struggle with, 465, 468, 470, 472

Enzymes, 264–267, 268–270, 272, 282, 441, 550

Eoanthropus, Dawsoni, **746**; *see* Piltdown man
Eohippus, **717***, **718***, 723, 730
Epidermal cells, 206*, 357
Epidermis, **193***, 194, 201, **322**, 342, 349*, 354, 474
Equal division, 411
Equus caballus, **717**
Eras, **628**, 629, 632, 635–643, 721*, 723
Erosion, **614**, 615, 616, 624
Esophagus, *see* Oesophagus
Essential organs (flower), **439**
Eugenics, 696, **757**, 758, **768**, 770
Euglena, **124***, 127
European cornborer, **542**, 598, 599
Europeans, 772
Euthenics, **768**, 771
Evaporation, **323**, 325, 327, 345, 346
Evening primrose, **685**, 686, 689*
Evergreens, **142**, 154, 155, 157, 344, 352, **472**
Evolution, 697–743; animals, 428, 433, 436, 437, 716–720; birds, 432, 433; embryo, 431; horse, 716–718, 724; individuals, 648, 649; man, 744–756; new types, 707–710, 724–733; organic, **726**; organs, 429; origin through, 570; plants, 443, 733; reading on, 570, 743; stages of, 435–437; theory of, 726, 732, 741, 742
Excavating, 748*
Excretion, **291**, 320, 321, 327, 343, 356, 519, 520, 531, **548**; *see also* Wastes
Excretory organs, **321**, 424*
Exhaling, 310*, **312**, 317
Exhibit from Nature Trail, 11*
Existence, 361; struggle for, 450, 451
Exoskeleton, 463, 637, 741
Experience, 390, 391
Experiment Stations, 537, 546
Experiments, 78, 207, 208, 251–253, 335, 341, 404, 407, 409; behavior, 359*, 362, 366, 367, 377, 378, 383–385, 387, 388; breeding, 661–675, 681; diseases, 481, 501, 507, 509–512; mutations, 683–686; plants, 705–709; X-Rays, 683, 684
Explorations, 1–12
Extermination, insect, 537–547; mosquito, 541, 542
External fertilization, 435, 452
Extinction, dinosaur, 642; species, 450; wild life, 603, 604
Eyes, 38*, 39*, 68*, 91, 100, 101*, 102, 112*, 374*, **375**, 377

Fabre, Jean Henri, 7, 8, 587
Fallow (land), **577**
False Solomon's seal, 606*
Families, **18**–20, 735; animals, 27, 28; man, 20; plants, 143–152, 156
Family, life, 453, 454*, 455, 459; size, 459, 767
Farm Friends and Foes, 547
Fascicled root, **202**
Fats, **184**, 187, 188, 209, 214, 248, 272, 303
Fauna, **468**, 470, **738**
Feathers, 36, 38*, 48, 489*, 491
Feeble-mindedness, **761**, 762, 766, 767
Feet, 27, 28, 103, 104
Fehling's solution, 187
Felis, **17**, 23, 736; *see also* Cats
Female, cells, 420, 421, 423; crayfish, 455; frog, organs, 424*, 435; gametes, 423, 440, 441, 657; male and, 424; mosquito, 479, 480*; primary sex cells, 657*, 673
Fenton, Carroll Lane, 632, 647
Fermentation, **126**, 522
Ferns, **135***–139, 412, 413*, **438**–450, 639*
Fertilization, 421*, 434, 435, 757; animals, 422, 430, 431; artificial, 430; double, **447**; external, 435, 452; fishes, 426, 427, 428*, 429*, 430; flowers, 442, 443; frogs, 431*; internal, 431
Fiber, 349, 351; tissues, 562
Fibrin, **294**
Fibrovascular bundles, **349**, 350*, 352–354
Fiddler crab, **101***
Field Museum, 646
Fife, David, 706
Filaments, gill, 318
Filial generation, first, **665**, 666–668, 669*, 671*; second, 667, 668, 669*, 671*, 673, 679*
Filterable viruses, **512**

Finger bones, bats, 33*
Fins, 65*, 69*, 70
Fire, experiment, 769*; salamander, 489
Fish, **65**–71, 153, 218, 221, 223, 314, 428, 463*, 470, 473, 482, 607, 721*; "age of," 638; bait, 222; brain, 564*; colors, 467*, 468; embryo, **429**, 436; fertilization, 431, 432; germplasm, 650*; heart, 735*; laws, 606; migrations, 70; mouth, 219*, 428; parental care, 455; reading on, 71, 72; reproduction, 425*–429*, 430; skeleton, 562*
Fish-hook cactus, 470*
Fission, binary, **410**, 417
Fitness, and survival, 728, 729*, **730**–732; to environment, 741; *see also* Adaptations
Fittest, survival of, **729**
Five-rayed animals, 107–109
Flagellum, 124*
Flamingo, **39**
Flatfish, 68
Flatworm, **111**, 415; *see also* Planaria
Fleas, **82**, 478, 529, 535
Flies, **77***, **78**, 91, 409, 456; fruit, **670**, 671*, 682*, 683, 684
Flight, 47*, 48, 76, 77
Flora, **468**
Floral envelope, **438***
Flounder, 68*
Flowering plants, **140**–156, 344, 438–450, 456, 457, 471, 658; reading on, 156, 157, 460, 464, 499
Flowerless plants, **129**–138; reading on, 138, 139
Flowers, 156; color, 661–663
Flying, birds, learning, 453; fish, 68; mammals, **33**, 34
Focusing, 559
Foes, *see* Pests
Food vacuole, **283**, 284*, 288
Food-chains, **474**, 580, **581**, 582, 584, 586–588, 599, 608
Foods, 143, 144, 148, 149, 532; calories, 246; canning, 524, 525, 533; care of, 527*, 534; diets, 242, 243, 246–250; digestion, 261–289, **548**, 586; energy, 257; inspection, 529; of animals, 212–223, 468; of plants, 191–212, 469; reading on, 260, 289; stimulus, 358; storing, 428, 429, 442, 443, 448, 457; substances, accessory, **214**; table of, 244–245; vitamins, 251, 252; *see also* Diet
Foot, *see* Feet
Footprints, fossil, 620*
Force, **231**, 232; *see also* Pressure
Forests, 589*–591, 592*, 599, 601*–602*, 603*, 607, 639; reading on, 156, 599, 608
Fossil Life and Modern Man, frontis.
Fossils, **619***, 620*, 621*, 622*–627*, **628**, 630–632, 647, 715, 716–719*, 720*, 721*–723
Four-o'clocks, 661–665, 678
Fox, red, 18*, 27
Fringed gentian, 363
Froglike animals, *see* Amphibians
Frogs, 60, 61*, 63, 318, 327, 374*; circulation, 304; digestive system, 282; dissection, 63, 221, 222, 407; heart, 301, 307; lungs, 318; reading on, 64; reproduction, 424*, 425*, 426*, 427*, 430, 431, 433*, 435, 437; skeleton, 562*; tree, 729*
Frond, 412, **444**
Fruit, **444***, 445*, 448, 457*
Fruit fly, 598, 599, 670, 671*, 682*–684; *see also* Drosophila
Fucus, **131**
Fumigate, **526**, 540
Functions, **168**, 176, 242, 267, 322, 326, 401, 404–407, 548–561
Fungus (fungi), 132, 133*–135, 477, 496, 507, 522, 597; reading on, 138, 139
Funk, Casimir, 251

Galapagos, 12, 740
Gall bladder, **270**, 275, 282
Galls, **496***, 499
Galton, Sir Francis, 756
Game, laws, 605, 606; trails, 12
Gametes, **418**, **419**–423, 426–429, 440, 441, 446, 655–657, 664*, 665, 672, 673*, 675*, 678
Ganglion, 370*, 405
Garbage, *see* Refuse
Garden, City, 157; Family, 156; peas, **148**, 666, 667
Garter snake, **54***, 55
Gases, 186, 188, 202, 203, 312, 343

Gastric juice, **271**, 276, 280
Gastrula, **427**, 428*, 436, 437, **564**, **648**; *see also* Cup
Gelatin, 502, **552**
Generation, spontaneous, **408**, 409, 510
Generations, 429, **445**, 446, 648–660, 665*
Genes, **658**, 675*, 767*; combination, 678, 766; linked, **675**; make-up, 659; in mitosis, 660; mutations, 681–688; recession, 701; theory, 676; transmission of, 661–681
Genetic make-up, 677, 678, 687, 688, 692
Genetics, **677**, 766–768; reading on, 696, 772
Genus (genera), 15, **17**, 19, 22, 23, **566**, 733, 735
Geologists, 628–632
Geology, 632
Geometrid moth, 489*
Geotropism, **364**, 367
Geraniums, **168**, 210
Germ cells, **649**; theory, **507**–511, 521
Germinal variations, **731**
Germination, **444**, 449, 450
Germplasm, **649**, 650*, 651, 659, 684, 686, 691
Germs, 508–511, 519, 521, 526
Giant, anteaters, **30**; egg cells, 432; tree frog, **61***
Gigas, **686**
Gila monster, **57**
Gills, **65**, 221, **314**, 318, 319, 433, 464, 637
Giraffe, **731***
Glacial age, **644**, 645
Glaciers, **613***, 644, 645
Glands, **270**, 278, 283, 340, 341, 561; adrenal, 338; digestive, 277; ductless, **336**; endocrine, 331; green, 326; mammary, 20; parathyroid, 340; pituitary, 336, 337; poison, 487, 488; salivary, 270; sex, 339; sweat, 322; thymus, 340
Glucose, 275, 276
Glycogen, **276**, **334**, 338
Goats, 592
Gobi Desert, 12, 625, 626, 627
Goiter, **332**, 336, 340, 341
Goldenrod, 496*, 582*, 733
Goldfinch, **47**
Goldfish, **65***, 70, 71, 223, 304
Gopher, 16
Gorgas, W. C., 546
Gorilla, 25*
Grafting, **711***, 712
Grain elevator, 236*; pollen, 440*, 441; wheat and oats, 706*
Grand Canyon, 623, 624*, 632
Grandparental, combination, 674; plants, 673
Granite, **619**
Grapes, 705, 706
Graph, **690***, 761*
Graphite, **635**
Grasses, 144*, 154, 156
Grasshoppers, 74*, **80**–82, 91, 215*, 221, 434, 456, 545
Grassroot Jungles, 93
Gravity, 362, **364**, 462
Grazing animals, 454, 486, 592, 593, 598
Green, frog, 60*; glands, **326**, 327; hydra, 586; leaf, 223, 357; plants, 222, 227, 549, 578, 579, 581; sea lettuce, 132; *see* Thallophytes
Gristle, 66
Grizzly bear, 35
Ground squirrel, 35, **51**, 331*
Groups, 17, 23, 132, 135–137, 141, 142, **751**
Grouse, spruce, 489*
Growth, **186**, **224**–242, 349–353, 483, 506
Guano bed, **578**
Guard cells, 203, 346
Guinea pigs, 249*, 260, 666, 679; reading on, 260
Gullet, **122**
Gulls, **39**, 40
Guppies, **68**, 437
Guyer, M. F., 561, 771
Gypsy moth, **541**, 543, **596**, 597

Habits, **392**, 393, 472; breaking (unlearning), 394, 398; health, 527; insects, 537; learned, 392; wild animals, 35
Haeckel, 569
Hair, 21, 326, 454, 478*, 485, 488, 489, 491, 583*, 674*, 682
Halibut liver oil, 253

Halters, 77*

Haploid, number, **656**; nuclei, 657, 658; sperm, 684, 685

Harvestman, *see* Daddy longlegs

Harvests, Cargoes and, 609

Harvey, William, 307

Hastings, G. T., 34

Hatchet foot molluscs, **103**

Hawaii, 600, 611

Hawks, **37**, 221, 223

Hay infusions, **121**, 127, 587

Head, tapeworm, 483*

Headlight, 467*

Health, reading on, 260, 289, 357, 407, 499, 547; rules, 528

Heart, 36, 165*, 295*–299, 301, 304, 305–307, 434, 735*; reading on, 357

Heartwood, 352*

Heat, 233, 237–239, 241, 364, 437, 444, 448, 506

Heath hen, 603

Hedgehogs, **30**

Heidelberg man, **747**

Hemiptera, **82**, 83

Hemlock, 141*

Hemocyanin, 567

Hemoglobin, **293**, 567

Hemophilia, **677**, 680

Hens, 435, 436

Hepatica, 605*

Herbivorous animals, **285**, 288, 292, **476**

Heredity, 661, 666, 676, 701, 763, 766; environment and, 648–696; reading on, 696, 770, 772; *see also* Inheritance

Herring, **67**

Hessian fly, 77*, 598, 599

Hibernating animals, **51**, **233**, 315, 331*

Hickory, leaf, 146*

Hillside gone to waste, 591*

Hilum, **447**

Hog-nosed snake, 54*, 55

Hogs, 693*

Hominidae, **21**

Homo, 21, 747, 748; Heidelbergensis, **747**; Neanderthalensis, **747**; sapiens, **21**, 749–751

Hooke, Robert, 169, 170, 171, 177

Hooks, tapeworm, **482**, 483*

Hookworm, 478, **481**, 482, 484, 485

Hormones, **277**, 329, 331, 334, 337, 340, **424**

Horned toad, **57**

Horses, 516, 519, 644*; bleeding, 516*; breeding, 702, 703*; fossils, 716*–718; reading on, 743

Horsetails, 139

Hospitals and disease, 523

Hosts, **475**–478, 481, 484, 491, 492, 495, 507, 522, **582**, 583, 587, 597

Housefly, **77**, 217*, 534

Howard, Leland O., 535, 537, 545

Human, beings, 454, 455; body, 260, 289, 357, 407; brain, 400*; carriers, 527, 528, 532; egg, 426*; heart, 307; progress, 772; race, 766–769; *see also* Man

Hummingbirds, 43, 44*

Humus, **580**, **591**

Hunger Fighters, 743

Huxley, T. H., 98, 99, 549, 560

Hybridized plants, 696, **707**, 733

Hybrids, **663**, 664, 665*, 666*–668, 673, 678, 702*, 708–710

Hydra, **115**, 118, 283, 284*, 288, 374, 377, 426*, 586*

Hydrate, 184

Hydrochloric acid, 187, **271**, 280

Hydrogen, 187, 573

Hydroids, 585*

Hydrophobia, **512**; *see also* Rabies

Hydrotropism, **364**, 467

Hyphae, **412***, 416, **477**

Hypocotyl, **447**

Hypothesis, **207**, 318

Ice, crevasse, **623**; sheets, 645*

Ichneumon fly, 456

Identical twins, **764**, 765*, 770

Igneous rocks, **619**, 631*

Immunity, 494–496, 511, **515**, **516**, 521

Immunization, **513**, 518, 522

Importations, harmful, 595–597

Imprints, fossil, **620***, 632, 640*

Improvement, human race, 756–772; plants and animals, 698–715; reading on, 772

Impulses, **368**–370, 372, 373, 380, 398

Inbreeding, **700**–704

Incas, **756**

Incisors, **278**

Incomplete, dominance, **667**; metamorphosis, **434**
Incubation period, **433**
Independent assortment, **674**
Indian pipes, 287*
Industry, 588, 589, 598
Infantile paralysis, 319
Infection, 498, 522
Infectious diseases, **507**, 523, 526
Influenza, 495
Infusion, **121**, 127, 587
Ingestion, **548**
Inhabitants, 610–647
Inhaling, 310*, **312**
Inheritable changes, 682*, 730, 731
Inheritance, blending, 667; characters, 666, 691, 692, 694, 695, 713, 738–766; disease, 759, 760; law of, 669, 674*; sex, 676; *see also* Heredity
Inner ear, **376**
Inoculate, **511**
Inoculations, 513, 515, 518, 520, 525
Insanity, **761**
Insectivora, **29**, 30
Insectivorous plants, 157, **287**
Insects, 73, **74**–93, 153, 377, 380, 496*, 537; blood, 303; breeding habits, 541, 542; characteristics, 74, 75; complete metamorphosis, **434**; development, 75, 76, 430, 432; extermination, 537–547; harmful, 535, 536, 545, 593, 599, 607; immigrant, 597, 598; importations, 600, 601; migration, 546; mouth parts, 222, 544, 545; pollination, 441, 446; protection, 488; reading on, 92, 93, 407, 547, 609; social, 85, 92, 455; wintering, 538, 541–543
Insoluble substances, **199**, 263, 273, 275, 287, 334
Instinctive behavior, **382**, 383–386*, 398, 399; *see also* Reflexes
Insulin, **334**, 336, 341
Intelligence, quotient, **760**, 761*, 766, 770; tests, 767
Intercellular, **173**, 174, 177
Intermediate products, **272**
Internal, fertilization, **431**, 432, 435, 541; organs, 405, 406; secretions, 329, 331
Intestinal, diseases, 533; juice, 273
Intestines, 268, 272, 273, 277, 282, 296*, 519, 531
Invertebrate animals, **73**–119, 153, 415, 423, 435, 455, 467, 719, 723
Invisible foes, **491**, 497; organisms, 120–128; parasites, **491**
Involuntary muscles, **405**, 406
Iodine, 132, 175, 176, 185, 187, 188, 331, 340
Iowa Cornfield, frontis.
Iron, 187, 192, 193; age, **755**, 772; lung, 319
Irradiation, **254**
Irritability, **360**, 362, 369, **550**, 561; *see also* Response
Isolation (quarantine), **526**
Ivy, Boston, 202; English, 202; poison, **486**, 487*, 497

Jack-in-the-pulpit, 606*
Japanese beetle, **541**, 598, 599
Java man, **745**, 746*
Jaws, 54, 486
Jellyfish, **114**, 115*, 467
Jenner, Edward, 514*, 515, 521
Jennings, H. S., 368
Jimson weed, 685*
Johannsen, 689
Joshua tree, 469*
Juices, 270, 271, 273, 276, 278, 280, 281
Jungles, 93

Kallikak family, 762, 763, 771
Kallima butterfly, **490**, 741*
Kangaroo, **31**, 454*, **469**, 594, 738
Kanred wheat, **707**
Katydid, **90**
Kelp, **131**
Key, **23**, 138, 155, 156
Kidneys, **321***, 325, 326, 327, 334
King Tyrant reptile, **642**
Kingdoms, **18**–20, 153; animal, 19, 21, 22; phyla of, 18–20; plant, 19–22, 129, 137
Kissinger, John R., 528
Knight, Charles R., 623
Koala, **739***
Koch, Robert, **501**–503, 507–511, 513–515, 521–523, 533
Krakatoa, 611

Laboratory, 120, **159**, 160*
Lacteals, 274*, **291**, **303**
Lady's slipper, **142***
Lamarck, Jean Baptiste, 690–691, 695
Land, 461, 464, 473, 588–593, 612–616; animals, 431, 451, 461–464, 473, 622
Langerhans, 335, 336
Larva, **75**, **78**, 86*, 481, 482, 538*, 540, 542*, 545, 594, 677
Lassos, poisonous, **488**
Lasting immunity, **495**
Latrans, canis, 17*
Lava, **611**, 612*, 617
Laveran, Alphonse, 481
Law of, dominance, **667**, 668; independent assortment, **674**, 675; inheritance, 669, 674*; segregation, **668**–671; unit characters, **674**, 675
Laws, bird, 605; game, 605; Lacey, 605; plant patents, 714; wild life, 607
Layer, **414**
Layering, **414**
Lead, 628, 632, 635
Leaf, 143*, 146*, 155, 206*, 210–212, 226*, 353, 368, 414, 415*, 416, 443, 469, 487*; cells, 265; plants, 672*; prints, 11*; reading on, 223, 357
Learning, 385, **386**–399, 455; complete, 391, 392; conditioned, 385; curve, 397; short cuts, 389
Leaves, 589*
Leech, **111**
Leeuwenhoek, Anton van, 120, 162, 169, 177, 409, 500, 553
Legs, bones, 716*, 717; insects, 74, 75
Leguminous plants, **576**, 580
Lemming, **585**
Lens, eye, 375*
Lenses, 550*
Lenticils, 193*, **194**, 205, 342, 343, 464
Leonardo da Vinci, 620
Leopard, 15*
Leopard frog, 655
Lepidoptera, **78**–80
Lessons, learning, 394–396
Lice, **82**, **478***, 485, 535
Lichens, **134***, 135, 138, 139
Life, ancient, 629; balance of, 580–599; city, 588, 598; cycle, 670; evolution, 743; functions, **549**, 550, **557**; necessities of, 473, 475; reading on, 190, 223–260, 289, 357, 609; Science of, 460, 499, 609, 647, 696, 743; web of, 580, 587; wild, 603–605
Lifeless things, 167, 188, 408–410
Light, 208, 209, 212, 230, 233, 237, 416, 449, 467, 689, 692; response to, 360–363, 368, 377; ultraviolet, 253, 633, 634
Lignin, **344**
Lily, 438*
Limestone, **113**, 128, 616, **619**, 622, 631*
Linkage, **675***, 680, 681
Linnaeus, Carolus, **1**, 16–19, 24, 568, 569, 735, 736
Linseed oil, 150
Lipases, **272**
Lister, Sir Joseph, 513, 514, 521, 522
Liver, **270**, 275–277, 282, 335
Living matter, **181**–188, 360, 550, 634; things, 13–22, **167**–178, 224, 235–237, 261, 287, 358–410, 465–468, 485, 548–570, 580, 615–620, 633, 648–661; reading on, 12, 93, 102, 128, 139, 157, 547, 570, 743
Lizards, **56**, 57*
Lobsters, 94, **98**, 99*
Lockjaw, **519**
Locomotion, 463*, 486, 549
Locusts, **80**, **82**, 83
Loeb, Jacques, 430, 437, 560
Long-winged fruit flies, 671*
Low power (microscope), 559
Lumbering, clean, 603*
Luna moth, 78*, **79**
Lungfish, **69***, 71
Lungs, 300, 301*, **308***, 309*, 310, 313, 315, 317; amphibians, 315, 318; birds, 36; fish, 69
Lymph, **301**, **302***, 303*, 307, 321
Lymphatics, **302**, 303*
Lynx, Canada, 28*
Lysins, **494**

Macrospore, **446**
Maggots, **408**, 409
Main streams of life, 561–563
Malaria, **421***, 479, 480*, 481, **483**, 484, 528
Malpighi, Marcello, 169, 553

Mammals, **20**–36; 315, 325, 563, 721*, 734*, 738, 739; "age of," 642, 643*, 644; brain, 399–401, 403, 406; heart, 735*; parental care, 453, 454; protection, 486, 487; reading on, 35; reproduction, 431, 454

Mammary glands, *see* Milk

Man, as breeder, 713; behavior, 390–396; circulation, 290–307; classification, 20–22, 749–752; diet, 242–260; digestive processes, 268–283; disease and, 500–547; environment, 688–696, 768; evolution, 722; food getting, 219*, 220; inheritance, 756–768; insects and, 534–547; nervous system, 371*, 399–401, 403, 405*; parasites and, 474, 478–483, 485; prehistoric, 744–749; reading on, 547, 608, 772; sense organs, 375, 377; sperm cell, 425*; unbalances life, 587–604; vestigial structures, 737

Mann, Paul B., 24

Manson, Patrick, 481

Mantis, praying, 80*

Many-celled animals, **117**, **368**; behavior, 374, 376, 380–399; digestion, 283, 284; reproduction, 415–431, 434; structural similarity, 558, 561

Maples, 143*, 146*, 457*

Marble, 616, **619**

Markings, butterflies, 491*; feathers, 489*; Siamese, 674*, 682

Marsupials, **31**, **594**, **739**

Master ductless gland, 337

Materials, earth, 571–580

Matings, 665*, 666, 701

Maturation, **656**, 657, 660, 684, 757

Mature, **658**

Mayas, **756**

Maze, 387*, 397*, 399

McGregor, J. H., 746

Meadow, 615*

Meat eaters, 486

Medicine, 481, 547

Medulla, **399**, 400

Membranes, 33*, 196–199*, 200, 203, 204, 270*, 309, 436, 437; cell, 262, 555*, 557*; mucous, 176, 178, **269**, 317; nuclear, **556**, 557*

Mendel, Gregor, 666–675, 696

Meninges, **406**

Meningococcus, 494*

Mental traits, inheritance, 760–766

Merino sheep, 698*

Meshie, 25

Mesoderm, **428**

Mesozoic era, **629**, 639, 640

Metabolic, cells, 557, 558; functions, 548, 558

Metabolism, **329**, 333–335, 340, 341, **548**

Metamorphic rock, **619**, 624*,630,631*

Metamorphosis, **228**; frog, 437; incomplete, **434**

Metchnikoff, Eli, 492, 499

Mexican bean beetle, 536*

Mice, **29**

Microbes, 128, 177, 460, 499, 547, 570

Micrology, 561

Microorganisms, **121**–128, **491**, 492, 507, 510, 523–534

Micropyle, **442**, **447**

Microscope, 128, 161, **162***, **163***, 175, 306, 500, 501, 520, 550*, **558**, 559, 561

Microscopic, organisms, **120**, 123; plants, 126, 470

Microscopy, Aquatic, 128, 570

Microspore, **446**

Middle Life, 629

Midget, 337*

Migrations, birds, 44, 45*, 46*, 47, 605; fish, 70; insects, 546; reading on, 50, 72; routes, map, 46*

Mildew, **134***

Milk, 258–260, 454, 526, **529***, **530***, 532; glands, 20

Mimicry, **490**, 497, 498

Minerals, 188, 192, 193, 200, 214, 248, 280

Miniature fruit fly, 682*

Mint family, **149**

Mirror, microscope, **559**

Missing link, **723**

Mitosis, **231**, **652***, **653**, 654, 659, 660, 684, 687, 757

Mitotic divisions, **657**

Mixture, **181**, 188, 189

Modern Life, 629

Modern Man and Ancient Life, frontis.

Moisture, **328**, 356, 444, 448, 449

Molars, **278**
Molds, 118, **133**, 134, 138, 188, 289, **412***, 416, 417, 419*, 478, 484, 506; reading on, 118, 128, 138
Molecules, **197***, 198, **199***, 203, 204, **572**
Moles, **29**, 30
Molluscs, 103–107, 153
Molting, **81**
Monarch butterfly, **490**, 491*
Mongoloid, **751***
Monocots (monocotyledons), **142***–145, 155, 156, 350*, **352**
Moran, John J., 355, 528
Morgan, Thomas Hunt, 658*, 659, 675, 684, 757
Mosquitoes, **77**, 78, 535; anopheles, **479–481**, 483, 528, 541*; extermination, 541, 542; larvae, 542, 546; mouth parts, 216*; pupae, 542–546; yellow fever, **528**, 533
Mosses, **135***, 136, 138, 139, 154, 412
Mother cells, **410**, 411, 416, 653
Moths, **78***, 79*, 80, 92, 215*, 231, 449, **538***, **540**, **541**, 545, 595, 596
Motor areas, **402**
Mould, *see* Molds
Mound Builders, **772**
Mountain, 624*, 631*; goats, 472; laurel, 606*; sheep, 19*, 472; tops, 472
Mouth, 176, 271, 491, 497, 526; fish, 219*, 428, 456, 467*, 468; grasshopper, 215*; insects, 222; mosquito, 216*; paramecium, **122**; plant, 193–196; tadpole, 433
Mucous membrane, 176, 178, **269**, 317
Mule, **710**
Mullein stalk, 476*, 485
Muller, Hermann J., 683, 687
Mumps, **281**
Muscle, 310, 337, 482, 519; cells, 176, 557, 568; smooth, **405**; striated, **176**, 405; tissue, 340, 561
Museums, Boy Scout, 9*; Natural History, 3*, 4, 22, 25; Outdoor, 7*
Mushrooms, 132, **133**, 137, 138, 139, 412, 417
Musk oxen, **471**
Muskrat, 595
Mussels, **465**, 466*
Mutant, **683**, 684, 686*
Mutations, **683**, 684, **685**, **686**–688, 704*–706, 712, 737
Myriapoda, **94**, 97, 98

Napoleon, 513, 592
Nasturtium plants, 363*
National Geographic Society, 71, 617
Natural, history, 24, 499, 608, 617; immunity, 495–496; selection, 726, **727**, 730–732, 741
Naturalists, 12
Nature, reading on, 12, 24, 35, 49, 499; Trail, 7*
Neanderthal man, 746*, **747**, 748, 749*, 753, 755
Nebraska, western, 644*
Needles, pine, 141*
Negative geotropism, **364**
Negro, 759
Negroid, **751***
Nemathelminthes, 111
Nephridia, 327
Nero, 334
Nerve, cells, 370, **371**, **373**, 557, 561; centers, **373**; fibers, **371**
Nervous system, 370*, 371*, 399–401, 405*
Nests, ants, 460; birds, 43*, 44*, 49; quail, 384*; stickleback, 456*; tent caterpillars, 543*; wasps, 386
Nettles, **485**
Neurons, **369***, 370–372*, **373**, 377, 379, 380*, 381, 396, 402
New York City, 589; death rates, 508*, 516*, 518; reading on, 64; Reservoir, 531
Nightshade, **148**, **486**
Nitrates, 192, 574–579
Nitrifying bacteria, **575**, 576
Nitrogen, 188, 573–575, 577*, 580
Nitrogen-fixing bacteria, **576**, 583, 584
Noctiluca, **125**
Nodes, 145*, **303***
Noguchi, 547
North American Mammals, 35, 634*
Nuclear membrane, **556**, 557*
Nucleolus, 555*, 557*
Nucleoplasm, **171**, **555**, 556
Nucleus, 171, 177, 226, 342, 555*, 557*; division, 410, 411, 443, 557,

652*, 653–655; fusion, 418–420*, 422, 423, 440, 442; sperm, **439**, 440, 447*, 440*, 447
Nutrients, **214**, 238, 240, 242, 262, 263–265, 266, 273, 287, 428
Nymphs, **81**

Oak, leaf, 146*; seedling, 445*
Oats, 447*, 706*, 709
Ocean, 628; life, 466–468, 470, 474
Oceanic angler fish, **467***
Octopus, **104***, **467**
Oenothera Lamarckiana, 685
Oesophagus, **268**, 282
Offspring, 450–459, 648–666*, 668–669*, 670–688; *see also* Parental care
Okapi, **731***
Omnivorous animals, **288**
One-celled, *see* Single-celled
Onion, 175, 415*, 416, 662*
Ooze, **466**
Operculum, **314**
Opossum, **31***, **738**
Opsonins, **493**, 494
Orange, seedless, **712**
Orchids, **144**
Orders, carnivora, 19*, **27**; chiroptera, **33**; coleoptera, **83**; diptera, **77**; hemiptera, **82**; insectivora, **29**; lepidoptera, **78**; marsupiala, **31**; orthoptera, **78**; platypus, **31**; primates, **21**, **25**, 746; rodentia, 21, **29**; ungulata, 19*, 21, **25**
Organic evolution, **726**, 727, 733
Organisms, **10**, **167**, 168, 170, **175**, 554; Behavior of, 407; many-celled, 410, 558, 561; microscopic, **120**–**167**; single-celled, 410–412, 558, 561, 570, 587
Organs, **167**, **168***–170, 173, 424*; breathing, 464; circulatory, 304, 306, 308; composition, 648; digestive, 270, 277; earthworm, 370*; essential, **439**; excretory, **321**; light-giving, 467; reproductive, 423, 435; sex, 340, 423, **649**; similarity in, 563, 564; vegetative, **414**
Orient, diseases, 528
Origin, earth, 633; reading on, 570, 743; species, **731**–743; through evolution, 715–724
Orthoptera, 80–82
Osmosis, **199**–201, 205, 262, 273, 291, 301, 431, 533
Osmotic pressure, **344**
Ostrich, **40**
Outbreeding, **702**
Outdoor museum, 7*
Out-of-Doors, 12, 35
Ova, **423**
Ovary, **423**, 434, 435; pistil, **440**, 442*, 444*
Overgrazing, **593**
Overproduction, **728**
Oviducts, **423**, 431, 435
Ovipositor, **488**
Ovules, **440**–442*, 443, 444
Owl, **37**, 38*
Oxidation, **235**, 236, 239, 242, 246, **261**, 262, 287, 308, 320–328, 331*, 334, 342, 343, **548**
Oxygen, 186, 291, 299–301, 308–319, 342, 356, 466, 525, 573, 579, 590
Oxygenated blood, **300**
Oxyhemoglobin, **293**
Oysters, 103, **104**, **108**, 117, 417, 533

Pacific Coast Animals, 119
Painter, T. S., 677
Paleolithic, *see* Stone Age
Paleontologist, 162, 164, 639, 716, 717
Paleontology, **620**
Paleozoic era, **629**, 634*, 635–638, 646, 720
Palisade cells, **211**
Palms, 154, 353*
Panama, Nature Studies in, 499
Pancreas, **270**
Pancreatin, **280**
Paramecium, **121***–123, 284*; behavior, 359*, 361; conjugation, 420*; culture, 417, 422; division, 410*; mouth, **122**; waste disposal, 325
Parasites, **475**–480*, 481–485, **491**, 496, 543, 544, **582**, 583, 586, 587, 597; reading on, 499
Parasitism, **582**
Parathyroid, **340**
Parental, care, 451–460; generations, **665**, 679
Park, William H., 517, 518
Parmelia, *see* Lichens

Parthenogenesis, **430**, **431**
Passive, gamete, **419**; immunity, **516**
Pasteur, Louis, 409, 509, **510–515**, 521, 547
Pasteurization, **530**
Pathogenic bacteria, **492**, 501, 502, 520, 521, 525, 526, 529, 530
Pavlov, Ivan, **163**, 164*
Peas, **198**, 230, 448, 666–668
Peat, **136**
Peattie, Donald Culross, 12, 22, 569, 608, 695
Pecan tree, 712*
Pedigree, **703**, **758***, 762, 763*, 770
Peepers, spring, 10*
Peking man, 746, **747***, 748, 753, 770
Pelican, 453
Pellagra, **252**
Penguin, **40***
Pepsin, **271**, 280
Peptone, **271**, 272
Perching birds, **41**
Perennials, **218**, 229
Periods, 629; Cambrian, **629**, 636*–638; carboniferous, **638**, 639*; Pre-Cambrian, **629**
Peristalsis, **273**, 282, 283
Persian cat, 15*, 674*
Pests, 595, 596; animal, 474–476; city, 589; control of, 599, 600; injurious, 483–484; insect, 534–537, 545, 546, 593, 596; invisible, 491, 523; microorganisms, 523–534; mollusc, 105; mosquito, 542; plant, 476, 477, 544; protection against, 483–491; reading on, 499, 547, 608; visible, 483
Petals, **438**, 443
Peter the Great, 133
Petrel, **40**
Petrifaction, **621***, 627*
Phagocytes, **492**, 493*, 494, 497, 499
Philippines, 466
Phoebe bird, 42*
Phosphates, **192**
Phosphorus, 192, 211, 571
Photoflash bulb, 10*, 63
Photomicrography, 570
Photosynthesis, **208**, 211, 233, 343, 346, 466, **549**, 584
Phototropism, 363, 366–368
Phylum, **18**, 19, **20**, 117, 119, **566**, **582**; annelida, **109**; arthropoda, **73**; bryophyta, **135**; coelenterata, **112**; echinoderma, **107**; mollusca, **103**; nemathelminthes, **111**; platyhelminthes, **111**; porifera, **116**; protozoa, **121**, 123; pteridophyta, **136**; spermatophyta, **140**; thallophyta, 130; vertebrata, **20**
Physical, basis of life, 549, 550, 553, 560; changes, 267; characteristics, 758–763; environment, 359, 360; Geography, 647; resemblances, 561–566
Physiology, 522, 560
Pigeons, 48, 259, 260; passenger, 603
Pigs, 255*, 454*, 482
Pigweed, 149*
Pike, Story of, 71
Piltdown man, 746*
Pine, 141*; beetle, 537; rust, 597
Pisces, **65**
Pistil, 438*, 440–442*, 443, 444*
Pith, 350*, **351***
Pithecanthropus erectus, **746**
Pituitary glands, **336**, 337
Placenta, **431**, 432, 448
Plagues, bubonic, 528, 529; locust, 81; reading on, 534
Planaria, **111**, 112*, 417; *see also* Flatworms
Plant, breeding, **667**, 672*, 698–700*, 707–710, 714; cells, 171, 175, 176, 342, 622*, 652*; diseases, 536; eaters, 25, 26; Industry, Bureau of, 714; lice, 82
Plant-animal relationships, 580, 583*, 592, 596, 598–609
Plants, **13**, 129–155; behavior, 362–366; chemical similarities, 567; crop, 593; diseases, 536; enemies, 476, 477, 478, 483, 484; environment, 461–474; evolution of, 724–733; fitness, 730; food, 191, 203; green, 222, 227, 549, 578, 579, 581; harmful, 544; higher, 342–357, 431; hybridization, 696, 707, 733; immigrant, 595–597; insect-eating, 287; land builders, 614, 615; leguminous, 576; life functions of, 549; many-celled, 561; mature, 658; microscopic, 121, 125, 126, 470; mimicry in, 497; mutations

in, 704–706; origin of, 715–724; parent, 413, 445; parental care, 456–459; protection, 485–499; reading on, 12, 139, 156, 499, 696; reduction division, 658; reproduction, 408–422, 444; single-celled, 410; survival, 461–499; tissues, 174, 177, 568; water, 131, 154
Plasma, **292**–294, 301–304, 493
Plasmodium, **479**
Platelets, 293*, **294**
Platyhelminthes, **111**
Platypus, **31**
Pleistocene age, **644**
Pleura, **312**, **315**
Plexus, **405***
Plumage, birds, 41, 339*
Plumule, **448**
Pneumonia bacteria, 126*
Poison, glands, 487, 488; ivy, **486**, 487*, 497
Poisons, contact, **538**, 546; parasitical, 478, 483, 486; stomach, 538
Polar, bear, 19*, **470**; bodies, **657**; life, **471**, **472**, 473
Polled (cattle), **704**
Pollen, **439**; case, **439**; grain, 440*, 441, 446; tube, **439**–442*
Pollination, **441**, 442, 446, 449, 471, 667, 681
Polluted, air, 589; water, **531**, 589
Pollywogs, *see* Tadpoles
Polydactyly, **759***
Polyneuritis in chicken, 250*
Ponds and Streams, 93, 102, 138, 499
Poplar leaf, 146*
Population, increase, 588
Porcupine, 68*, **487**, 488*
Porifera, 116
Pork, 482, 484
Porpoise, 737*
Portuguese man-of-war, **115**, 116*
Positive geotropism, **364**, 367
Potassium, chlorate, 186; iodide, 187; nitrate, **192**
Potato, **148***, 188, 414*, 416, 506; beetle, 598
Pouched mammals, **31***, **453**, 738, 739
Praying mantis, **80***
Pre-Cambrian period, **629**
Precipitation, **567**, 569
Prehistoric, ages, **744**, 745, 753–755; forms, 635–646; men, 745–750; reading on, 772
Preparation, food, *see* Digestion
Preserving foods, **523**, 524, 532, 533
Pressure, 311, 345, 353, 466–468, 503, 506, 524; osmotic, **344**
Prevention, disease, 508, 526–528
Prey, birds of, **37**
Prickly pear, 595*
Primary sex cells, **656**, 657*, 664*, 673*, 675*
Primates, 21, 25, 746, 747
Prolific reproduction, **458**, 485, 498, 535
Pronuba moth, 449
Propagation, vegetative, **414**, 415*, 416, 714
Properties, of elements, **179**
Protective devices, animals, 486–488; 489*, 490*, 491*–497; man, 507–547; plants, 485, 486*, 487*, 496, 497, 544
Protective resemblance, **490**, 498*
Proteins, **184**, 187, 209, 214, 247, 263, 264, 280, 293; synthesis of, 343, 345, **549**, 574
Proterozoic era, **628**, 635
Prothallus, **445**, 446, 448, 449
Protista, **569**
Protococcus, **130**, 138
Protoplasm, **170**, **172***, 175*–**182**, **186**, 187, **549**, 552*, 571; basis of life, 549; composition, 184, 185, 191, 553; early ideas, 550, 551; properties, 177, 264, 360, 369, 550, 552, 558; reproduction, **186**, 189, 648; structure, 550–553, 560
Protoplasma, **549**, 553
Protozoa, **121**, **123**–126, **154**, **549**; behavior, 358–362; continued existence, 361; malaria, 421*, 479–481, 484; parasitic, 475, 478–481; Polar regions, 470; response, 358–361, 364; shells, 551*; single-celled, 283, 288, 558
Pseudopods, **122**, 123, 127, **294**, 302, 358, 410
Psychology, 283, 407
Pteridophyta, **136**
Ptyalin, **271**, 279
Puerto Rico, 466

Puffball, 727*
Pulmotor, 319
Pulse, **296**, 305
Puma, 15*
Pupa, **75**, 86*, 542, 545
Pure, breeding, 665, 667, 668, 677, 687; culture, **503**, 506, 509, 511, 521, 534; Food and Drug Act, 524
Pus, **492**, 494*, 498, 513
Pyramidal cells, **401**
Pyrogallol, 317
Python, **56**

Quackery, 260
Quail, 384*
Quarantine, **526**, 532
Queen, ants, **86**, 455, 460; bees, **87**, 430
Queen Anne's lace, *see* Carrot
Quinine, 151

Rabbits, **29**, 585, 586, 588, 594
Rabies, **512**, 513, 515
Races, **21**; classification, **751**, 752; survival, 457, 766–769
Radiation, **324**
Rainfall, 347, 468, 469, 590
Rainier National Park, 471*
Rakers (gill), **318**
Raleigh, Sir Walter, 148
Ranges (barriers), **738**
Ratios, 663–665; Mendelian, 667, 684, 757
Rats, **29**, 218*, 247*, 248*, 252*–260, 397, 399, 485, 529, 669*
Rattlesnakes, 53*, **55**, 56*, 489, 498
Raven, Harry C., 25
Raw materials, 343, 344
Ray flowers, **151**–153*
Rays, **66**, 71; medullary, **351**; ultraviolet, 253, 633, 634
Reasoning, **390**, 391
Receiving gamete, **419**
Receptors, **368**, 374–378, 380*; earthworm, 374, 379; Hydra, 374
Recessive characters, **666**; condition, 759; genes, 677, 683, 687, 701
Recombinations, 678, 681, 682
Red, corpuscles, 293, **303**, 498; Fife, **706**; newt, **60**; plasma, 293
Redi, **408**, 646
Reduction division, **656**, 657*, **658**, 660, 679, 680, 681, 685
Redwoods, giant, 228*
Reed Commission, 485
Reflex, arc, 380*, **381**, 396; behavior, 404
Reflexes, **359**, 361–364, 381, 382; conditioned, 385, 387, 398, 399*; in higher animals, 384, 385, 396–399
Reforestation, **603**, 608
Refuse heaps, 744
Regeneration, 415, 417
Reindeer, **26**, **471**
Relationships, balance in, **588**; biological, 588, 604; changing, 584, 585, 593; disturbance in, 584; food-chain, 580, 581; harmful, 588–593; one-sided, 581; plant-animal, 580, 583*, 592; symbiosis, 583, **584**; unbalanced, 601
Relatives, mating, 701
Remains, 619–623; cliff dwellings, 754*; fossil man, 745; reconstructing from, 626, 627
Remoras, **69**
Reproduction, **186**, 189; ameba, 410; animals, 422–437; bees, 430; birds, 432; by fission, 410; complicated, 422, 423; fish, 429*; frog, 424*, 435; insects, 535; invertebrates, 415; male in, 420–424*, 440, 441, 657*, 673; methods, 408–417, 434, 435; organs, 423; paramecium, 410; plant lice, 430; plants, 413, 414, 444–446; process, 435; prolific, **458**, 485, 498; reading on, 460; regeneration, 415; sexual, 422–437; simplest, 410, 418, 419; successful, 450–460; vegetative, 415; wasteful, 458; yeast plant, 411*
Reproductive organs, **423**; bees, 430; cells, **649**; chicken, 435; embryo, 442, 443; frog, 424*, 435; hen, 435; plant, 438, 439; tapeworm, 484
Reptiles, **51**–64, 153; age of, 639–642; brain, 564*; desert, 469; heart, 735*; polar, 471; reading on, 12, 64; reproduction, 432, 459
Resemblances, characteristics, 550, 562; chemical, 567; family, 649–651, 677; protective, **490**, 498*; structural, 561–566

Reservoirs, 531, 617
Resin, **142**, 622
Respiration, 319, 343, 356, **548**
Response, 358–380; ameba, 362; experiments, 362; many-celled animals, 368–380; paramecium, 361; plants, 362, 363*, 364*; protozoa, 358–360, 364; to chemicals, 361; to climate, 358, **359**, 360
Resting cells, **430**, 444
Retina, 375, 378, 379
Rhinoceros, **25**
Rhizopus, *see* Mold
Ribbons, 464*
Ribs, 52*, 311, 316
Rice, polished, 250, 251
Rickets, **253**, 254*, 255*, 258
Rigid, plants, 346; substance, **296**
Rings, **145***, **349**, **350**, 351*, 352*
Ringworm, 478
Rockefeller Foundation, 485; Institute, 164, 165
Rocks, 112, **234***, 613*, 614*, 618*, 619*–632, 717–722
Rockweed, **131***, 464*
Rocky Mountain, goat, 472*; Trees and Shrubs, 156
Rodents, **29**, 472
Roots, 197, 202, 210, 230, 280, 342, 354; hairs, **195***, 196*, 200*, 205, 343; in reproduction, 414, 445; petrified, 621*; pressure, 344, 353; response of, 367; structure, 354; systems, 468; tap, 194*
Rose family, **147***
Ross, Ronald, 481
Rotifers, **289**
Roughage, 249, 275, 284
Roundworms, **111**, 118
Rubber, **150**
Ruins, 756
Runner, 413*
Russian Wolfhound, 338*
Rusts, 496, **597**

Sabin, Florence Rena, 161*
Sacculina, **484**
Salamander, 60, 64, **489**
Saliva, 163, 164, **271**, 276, 279, 282, 378, 397
Salivary glands, **270**, 277, 480*, 677
Salmon, **70**, 72, 460
Salts, 320, 323
Sanctuaries, **605**
Sandstone, 618, 619, 624*, 627, 631*
Sapwood, 352*
Sawfish, **66**, 67
Scales, fish, 463; insect, 78, 82, 539, 540*, 600; vertebrate, 491
Scavengers, **294**
Schick, Bela, 517; test, **518**
Schleiden, Matthias, 554, 726
School, buildings, 768*; Nature League, 241
Schultz, Max, 553, 554
Schwann, Theodor, 554, 726
Science, and disease, 500–523; reading on, 223, 450, 460, 499, 547, 609, 647, 687
Scientists, 178–190, 597
Scion, **711***, 712
Scouring rush, 136*
Scurvy, **249***, 257
Sea, anemones, **112**, 113*, 188, 288, **465**, 466*; animals, 31–33, 112–116, 466–468; fossils, 623; gull, 47*; horse, 67*; lettuce, 132; microorganisms, 124, 125; reading on, 102, 119, 138, 499, 608; squirts, 466*; turtle, **58**; urchin, 109*, 436, 437, 470
Seals, 32*, 313, **470**
Sears, Paul, 599
Seaweeds, **131**, 132, 137, 154, **464**, 465
Secondary, growth, 352; sexual characters, 423–425*, 436
Secrete, **264**
Secretin, **277**, 329, 341
Secretions, **264**, 265, 270, 276, 323, 327, **329**, 338–340, 488, 548–550, 561
Sediment, **618**
Sedimentary rock, **618**, 619, 623, 624*, 627–630
Seedlings, 230, 354, **444**, 448
Seeds, **444***, 457*; coats, **444**, 445*; dispersal, 457, 458, 460; germinating, 195*, 230, 356, 443*, 449, 616
Segments, **74**, 91, 110, 111, 482, 483*
Segregation, **668***, 669–671, 683
Selection, improvement by, 698–704, 709; natural, 726, 727, 731
Self-pollination, **441**, 446, 471, 667, 681

Semicircular canals, **376***
Semmelweis, 513
Sensation, **548**
Sense organs, 375, 379
Sensitive plant, 368
Sentinel pine, 693*
Sepals, **438**
Serum, **294**, 517, 525, 526, 527, 569
Seventeen-year locust, **82**, 83, 90
Sewage disposal, 520, 531*, 533
Sex, birds, 435; cells, 656, 657, 659, **664**; chromosomes, **676**; frogs, 435; glands, 339; organs, 339, 340
Sex-linked characters, 677
Sexual reproduction, 418; animals, 422–437, 648; plants, 438–450; simplest, 419*–422
Shale, **618**, 624*, 627, 631*
Shapes, bacteria, 502*; cells, 423, 554, 555, 657; differentiation in, 435; egg, 657; for speed, 463*; fruit, 669*; wings, 670, 671
Shapiro, H. L., 751
Shark, **66***, 71
Sheep, 19*, 511, 575*, 592, 596, 598, 698*, 704*, 710
Shells, 58, 63, 103, 106, 107*, 109, 113, 117, 123*, 432, 465; reading on, 119
Short-fingeredness, **759**, 770
Shrew, **30**
Shrubs, **140**, 156, 157, **472**
Siamese cat, 674*, 682
Siberia, 623
Sierra Junco, 41*
Sieve tubes, 348*, 349*, 350*, 351
Silkworms, **77**, 79*, 80, 92, 507, 522, 599
Similarities, *see* Resemblances
Single-celled organisms, 283, 288, 325, 410–412, 422, 558, 569
Sire, **703**
Six-fingeredness, 759*
Skates, **66**, 67*
Skeletons, 25*, 34, 73, 113, 117, 562*, 563*, 568, 622, 717*, 733, 737*
Skin, 54*, 60, 117, 315, 318, 322*, 326, 480*, 481, 486, 491, 526, 758, 770
Skull, **20**, **370**, 406, 747*
Skunk, **487**; cabbage, 486*
Slime, 463; mold, **550**
Slips, **413**, 416, **711**
Sloth, **30**, 583*
Slug, 106*
Smallpox, 514, 515, 517, 521
Smoke, 588*, 589
Smooth muscles, **405**
Smut, **477***, 478, 496
Snails, 103*, **104**, 720*
Snakes, **52***–54*, 55*, 56*, 62, 223, 306, 425, 489; reading on, 12, 64
Snapping turtles, 451*
Snow, plants in, 471*
Social insects, **85**, 455, 459
Soft-bodied animals, 103–106
Soil, 353, 356, 544, 572, 578*, 580, 646; bacteria, 575, 577, 579; compounds, 192, 573–579; conservation, 609; displacement, 612*, 614, 617; fertility, 576–579; nitrates, 575; top, 590*; water, **193**, 203–206, 345
Solar, plexus, **405***, 407; system, **633**
Solidago, **733**
Solomon's seal, 145*
Soluble, **199**, 263, 273, 287
Solution, 292, **551**, 552
Soma, **649**
Somatic, cells, **649**; changes, **691**; variations, **731**
Somatoplasm, **649**, 659*
Sorghum, **679**, 681
Soy bean, 698–700*, 702–704, 707
Sparrows, 453, 564*; English, **595**, 596
Spawning, **70**, **426**
Specialization of function, **561**
Species, **17**, 19–21, 424, 466, 566, **731**, 735; bacteria, 500, 509; desert, 470; importations, 594–596; insects, 535; invertebrates, 73; mammals, 642; man, **21**, 751–753; new, 713; number, 655, 656; origin, 725, 733–743; survival, 450; vanishing, 603, 604; varieties of, 20, **697**, 698, 750
Specific, antibodies, 498; lysins, **494**; opsonins, 391, **493**
Sperm, **423**, **440**, 441, 656, 657; cells, 424, **425***, 426, 430, 435; ducts, **423**, 435, 442; formation, 656, 657; haploid, 657; maturation, 656; nuclei, **439**, 440*, 447

Spermaries, **423**, 434, 435, **656**
Spermatophyta, **140**
Sphagnum, **136**
Spiders, **94**–96, 102
Spinal cord, 370, 371*, 512
Spindle, **654**
Spines, **469**
Spirilla, 494*
Spirogyra, **130**, 418*, 419–422, 427, 437
Spirostomum, **561**
Sponge, **116**–118, 154, 318
Spongy layer, **211**, 212
Spontaneous generation, **408**, 409, 510, 634, 646
Sporangium, **412**
Spores, **411**, 412*; bacteria, 503, 506; case, **412**, 413, 416; ferns, 444–446, 449; fungus, 477; molds, 506; moss, 135; mushrooms, 417; puffball, 727*; tetanus, 519*; typhoid, 522
Sporulation, **412**, 417
Spraying, **538**, 539*, 540
Spring peepers, 10*
Sprouting seeds, 195*, 356, 449
Spruce grouse, 489*
Squash, 669*; tendrils, 365*
Squirrel, 29, 35
Stag, 750*
Staining, bacteria, 501*, 504, 520; cells, 556, 561, 622*, 652*–655; technique, 501, 509
Stalk, contracting, 360*; filament, **439**
Stamens, 438*, 439*, 441
Staphilococcus, 494*
Starch, **182**, 183*, 184*, 187–189, 206, 208, 214, 266, 279, 280, 326, 560
Starfish, **107**, 108*, 415, 417, 435–437, 459, 636, 646
Starlings, 45*
Steam, heat, 328; pressure, 503, 506
Stems, 140, 202, **229**, 347–350, 355*, 413, 672*; desert plants, 468; dicot, 350, 351*, 355; for reproduction, 414, 416; growth, 230, 351, 352; monocot, 350*–352, 355; rooting, 413; woody, 350, 354
Stentor, **561**
Sterile, **710**
Sterilization, 189, 514, 524, 767
Stickleback, 456*
Stigma, **441**, 442*, 447
Stimulus, 358, **359**, **360**–364, 368–370
Stinkbug, **487**
Stock, **711**, 712*; racial, 22, **751***
Stomach, 269*, 271; birds, 222, 286; contents, 218*, 221; cow, 289; fish, 285, 468; improvised, 283; mosquito, 480*; poisons, 538; sac, 288; teeth, 285, 288
Stomata, 193*, **194**, 201, 202, 342, 343, 345, 347, 464, 473
Stone age, 745, **753**–755; reading on, 647, 772
Storing, experiences, 391; food, 428, 429, 442, 457
Strap, fruit fly, 682*
Strata, rock, **618***, 623, 624*, 629, 630*, 631*
Strawberry plants, 413*, 417, 700*, 713
Streamers, 116*
Streptococcus, 494*
Striated muscle, **176**, 405
String bean plant, 536*
Structure, 70, 117, 167, 168, 280, 314–318, 354, 356, 484, 491; adaptations in, 740; cells, 170, 554–556; differentiation in, 561; dinosaur, 641; insects, 92, 537; protoplasm, 551–553, 560; reading on, 570; resemblances, 558, 561–564, 720–723; underground plants, 194; useless, 736, 737
Style, **441**, 442*
Subdivisions, 22, **751**
Substances, 191, 292; rigid, **296**; soluble, 287; uncombining, 181
Successful reproduction, 450–460
Suckers, **482**, 483*
Sucking insects, **540**
Sugar, 178*, 181*, 183*, 187, 188, 197*, 199*, 214, 276; beet, 194*; cane, **144**; metabolism, 334, 335, 341
Sulphates, **192**
Sun, 588, 589, 633, 692
Sunflower, 364*, 705
Supplying gamete, **419**
Supporting, cells, 351; tissue, 349, 350
Surface, earth, 610–617
Surgery, 513, 514, 521

Survival, by adaptation, 464–472, 741; by reproduction, 450, 457; of the fittest, **729**
Swallowtail butterfly, 78*
Swamp, 615*, 617, 638, 639
Swarming, bees, **88**, 89
Sweat glands, **322**, 323
Sweetbread, 406
Swordfish, **486**
Symbionts, **583**
Symbiosis, **584**, 587
Synapse, **372***, 403
Synapsis, **656**
Synthesis, **206**, 210, 343, 345

Tables of food values, 244, 245, 257
Tadpoles, 59*, **60**, 340–344, **433***, 434, 436
Tailed amphibia, 59, **60**
Tailless amphibia, **60**
Tap root, beet, 194*
Tapeworms, **112**, 478, **482**, 483*, **484**
Tar Pits, Beasts of, 647
Tar pool, 622, 623*
Tarantula, **95***
Taste buds, **375**, 378
Techniques, 501, 507
Teeth, 28, 36, 220*, **278**, 279, 285; fish, 221; frog, 222; grinding, 25; in stomach, 285, 289; milk, 281; seal, 32*
Temperature, 62, 231, 360, 362, 366, 416, 422; body, 324, 325, 327
Tendrils, **364**, 365*
Tent caterpillars, 543*
Tentacles, 104*, 113*–115*, 116, 284
Termites, **88**, **89**, 90*, 267
Terrapin, 58
Terrarium, **63**, 587
Testis, **423**
Tetanus, **519**, 522
Thallophytes, **130**–135, 138
Thermotropism, **364**
Thigmotropism, **364**
Thistle, 38*
Thoracic duct, **302**
Thorndike, E. L., 387
Thoroughbred, horse, 703*
Thoughts, **402**
Thousand-legged arthropods, **97**, 98
Throw-back, **677**
Thymus gland, **340**
Thyroid gland, **331**, 332*, 333, 340
Thyroxin, **329**–333, 341
Tidal zone, life, 465, 474, 580; reading on, 119, 138, 499
Tiger, saber-toothed, 623*
Tissue, **173**, 174, 176, 177, 316, 561–563; cells, 302*, 557, 568, 648, 649; connective, 297*; elastic, 297*; skin, 322*; supporting, **463**; woody, **463**
Toads, **57**, 60, 61, 455*
Tobacco plant, 704, **705***
Tomato, ovary, 444*
Tongue, 28, 217*, 271, 278, 378
Top soil, **580**, 590*
Tortoises, **58**
Touch, organ of, 468; receptors, 378
Tourniquet, **306**, 307
Toxin-antitoxin, **517**
Toxins, 478, 479, 483, 484*, 492, 493, **516**
Toxoid, **518**
Tracheid, **344**, 353
Tradescantia, 202, 210, 555, 556
Trailing arbutus, 606*
Trails, Watchers of the, 35
Traits, *see* Characteristics
Transfusion, blood, 307
Translucent spot, **187**
Transmitters, **368**–370
Transpiration, **346**, 347, 353, 355, 469
Transportation system, animals, 290–307; plants, 343, 344, 347, 348
Traps, insect, 541, 542
Tree frog, 61*, 729*; of life, **722**, 724
Trees, 141*, **142**, 145, 146, 155, 156, **353***–355, 356, 469*, 547*, 586, 592*, 599
Trenches, fire, 603*
Trial and error learning, **387***, 388, 389*, 399
Triceratops horridus, 641*
Trichinosis, **482**
Trichocysts, 361
Trihybrid, **680**
Trilobites, **636***, 637*
Triploid number, **658**
Triton's trumpet, 107*
Tropical, Air Castle, 499; fish, **71**; Seas, 12; snakes, 57
Tropism, **363**
Trudeau, Edward Livingston, 523

Trumpeter swans, 452*
Trypsin, **278**
Tsetse fly, **535**
Tube nucleus, **439**, 440*
Tuber, 414, 416
Tuberculosis, **508***, 509, 510*, 521, 523, 530
Tubes, eating, 112*, 115*; for circulation, **290**, 291, 302*, 308*; plant, 344*; pollen, 423, **439**–442*, 446, 447
Tugboat, smoke, 588*
Tulips, 140*, **144**, 366
Tunnels, 537*
Turgid, 366; turgor, **366**
Turkey, bush, **383**
Turtles, **58***, 59, 64, 223, 307, 451*, 562*
Turtox leaflet, 49, 118, 178, 189, 460, 580, 681
Twins, *see* Identical
Tyndall, John, 409
Typhoid fever, 494*, 501*, **519**, 520*–522
Typhus, 535
Tyrannosaurus rex, **641***, **642**

Ultramicroscopic genes, **659**
Ultraviolet light, 253, 633, 634
Ulva, **132**
Under-water life, 5*, 6, 313, 462*, 636*
Unequal division, **411**
Ungulata, 19*, 21, **25**, 26
Unit, **158**; character, 674, 675; of function, 267
United States, Department of Agriculture, 49, 137, 223; Forest Service, 601; Geological Survey, 617
Unlearning habits, 294, 398
Uranium, **628**, 632
Urea, **320**
Uric acid, **320**
Urine, **321**, 334
Uterus, **431**

Vaccination, 514, **515**, 517, 520–521
Vaccine, **515**
Vacuoles, **171**, 283, 288, 555*, 556
Valves, 277, **297**, 298*, 299
Variations, **678**, 684, 687, 694, 727; genetic make-up, 688, 689; germinal, **731**; graph of, 690*; inheritance of, 730; in man, 689; Lamarck's theory, 690–691; Measurement of, 688, 689, 694; reading on, 696; somatic, **731**; types of, 732
Varieties, **21**, **697**, 701*, 706, 707, 713, 715, 743, 750
Vegetable eaters, **285**
Vegetative propagation, **414**, 415*, 416, 471, 710–714
Veins, 211, 291, 292*, 295*, 296*, 298*, 305, 349
Ventilation, 328
Ventricles, **295***, 298–301, 305, 306
Venus's fly-trap, **362**, 367
Vertebrae, **53**, 563
Vertebrates, 20–72, 153; Behavior, 374, 399; circulation, 303, 304, 306, 310; classes, 723; digestion, 288; fossils, 718, 719; heart, 735*; reproduction, 415, 423, 435, 437; structural resemblances, 562*, 566, 568, 569, 733–735, 743
Vestigial structures, **737**, 742, 743
Vestigial-winged fruit flies, 671*
Viceroy butterfly, **490**, 491*
Villus, **274***, 280, 283, 291
Vine, 684*
Vinegar fly, *see* Fruit fly
Virulent germs, **511**, 519
Virus, **512**
Vitamins, **251**–253*, 254–260
Voice box, 317, 322*
Volcano, **611**, 617
Voluntary muscles, **405**
Von Behring, Emil, 515, 517, 518
Von Mohl, Hugo, 549
Vorticella, 360*
Vulpes, 18*
Vultures, **38**

Wadlow, Robert, 330*
Walking stick, 490*
Wallaby kangaroo, 453*
Wallace, Alfred Russel, 3, 490, 726, 727, 733
Walls, 296, 297*, 301, 309*, 315, 343, 349
Wasteful reproduction, **458**
Wastes, 275, 282, **291**, 292, 320–328, 343
Water, 186–189, 192, 248, 292, **313**,

317, 622; aerated, **462**, 465, 466, 532; drinking, 520, 530; environment of, 461–463; evaporation of, 323, 326; polluted, 531, 589; reading on, 12, 609; soil, 193, 200, 203–206, 344, 345; transpiration of, **346**, 354
Water birds, 38; bugs, 83; cycle, 599; moccasin, **55**; molecules, 197*, 198, 199*
Water-living forms, 2, 131, 185*, 435, 459, 463–468, 473
Watermelon, **707**, 708
Watershed, 602*
Weakened germs, 511–513, 521
Weather records, 616
Weathering (rock), **614**
Weeds, 156, 476*, **477**, 485, 544–547
Weight, reducing, 256, **257**, 341
Weismann, August, 649, 686, 691, 692, 731, 732
Whales, **31**–33, 313, 470, 563, 736, 737
Wharfpile, 466*
Wheat, 189, 195*, 702*, **706***, 707
White ants, *see* Termites
White, cells, 493*; corpuscles, 492, 498; pine rust, 597, 598*
White-eyed fruit fly, 682*
Wild, animals, 35, 603–605*, 608; carrot, 124*; flowers, 156*; horse, 703*; life, 604
Wind-pollination, **446**
Windpipe, 308*, 315, 316, 332*
Wingless fruit fly, 682*
Wings, 77, 78, 670
Wood, 90*, 350*, 351*, 352–357
Wooly, aphid, 540*; elephant, 623
Work, **232**, 233
Workers, ants, **86**, 455; bees, **87**, 430
World, Almanac, 599; reading on, 12, 93, 102, 139, 157, 499, 743, 772
Worms, 109–111*, 112, **153**, 283, 423, 425*, 478, 481, 482, 587
Wren, Carolina, 42*
Wyandotte rooster, 339*

X-rays, for mutations, 683, 684; of lily, 438*; snake, 52*; tulip, 140*

Yeasts, **78**, 125, **126**, 128, 138; reproduction, 410, 411*
Yolk, egg, 432, 436, **657**; sac, **428**, 429*
Young, *see* Offspring

Zinsser, H., 485
Zoologists, **51**
Zoology, 71; reading on, 24, 189, 223, 289, 357, 407, 460, 547, 570
Zygospore, 419*, **420**, 422, **427**
Zygotes, **427**, **431**, 432, 435, 437, 445, 650*, 655, **657**, 660, 685

398013

Bi Kroeber,Elsbeth and Wolff,W.H.
K Adventures with living things.

University of Toronto Library

DO NOT
REMOVE
THE
CARD
FROM
THIS
POCKET

Acme Library Card Pocket
LOWE-MARTIN CO. LIMITED